

**QA/QC**

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Originated By: JRJ 12/20/21

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December 20, 2021

PS19-20316-0

Brian Bell  
Design Manager  
Flatiron-Lane Joint Venture  
400 Talbot Road South, Suite 400  
Renton, Washington 98055

Subject: **Bridge 28E – Low-Density Cellular Concrete Fill Addendum RFU**  
WSDOT I-405: Renton to Bellevue Widening and Express Toll Lanes Project  
Renton, Washington

1 Dear Mr. Bell:  
2 This addendum provides additional geotechnical design recommendations to the “released for use” version of the  
3 Geotechnical Engineering Report: Bridge 28 (Hart Crowser, a division of Haley & Aldrich, dated March 24, 2020)  
4 (submittal number 1169). This document is an addendum to that report.  
5 This addendum includes geotechnical recommendations for the use of low-density cellular concrete (LDCC) as fill  
6 material behind the east and west abutments of Bridge 28 East (BR 28E) to reduce the lateral pressure on the pile  
7 caps at each abutment and surcharge on the soldier pile wall. The analyses discussed in this report reflect the design  
8 alternative chosen and communicated to us by the project team via email on May 18, 2021, and preliminary sketches  
9 transmitted to us on May 20, 2021. We understand this option was chosen to support the wall design and was  
10 proposed by the wall designers and accepted by Flatiron-Lane Joint Venture (FLJV). These sketches are preliminary  
11 and intended for general reference only, and are provided in Attachment 1. A vicinity map, site plan, and subsurface  
12 profile for the BR 28E west and east abutments are provided in Figures 1 through 5, respectively. All subsurface  
13 data (boring logs, groundwater measurements, laboratory data, etc.) are provided in the appendices of the Bridge 28  
14 report.

## 15 **Structures Understanding**

16 We understand the soil behind the pile caps is being replaced with LDCC fill to reduce the lateral pressure on the  
17 pile caps therefore reducing the lateral deformation of the BR 28E pile caps. This intended result is to reduce the  
18 load on the MR-O and GR-O soldier piles and tieback walls in front of the bridge abutments. Based on the  
19 previously referenced May 20 email, we understand that the LDCC volume will be approximately 10.5 feet deep.  
20 However, other depths may be used for final design by the wall or bridge designers. Our recommendations are  
21 provided such that the wall designer can choose the appropriate LDCC width (distance behind the pile cap) for the  
22 wall design. The LDCC is planned to be placed against the bridge abutments after the pile cap is constructed and  
23 will not be structurally connected to the bridge abutment. Note that based on discussions with the structural  
24 engineer, we understand that it would be acceptable to place LDCC below the end diaphragm prior to the bridge  
25 being constructed, if desired.

## 26 **Soil and Low-Density Cellular Concrete Parameters**

27 This memorandum does not modify the soil parameters presented in the Bridge 28 report. For the LDCC, we  
28 recommend placement of Type III LDCC for use as fill behind the bridge abutments, with a dry density of  
29 35 pounds per cubic foot (pcf) or lower. The LDCC will have a cast (wet) density of approximately 5 pcf higher  
30 than the reported dry density, and we estimate the reduction in density will occur within 5 to 7 days. Any  
31 surcharging effect of the temporary higher unit weight on the bridge abutment shall be accounted for. We have  
32 assumed the LDCC acts as a cohesive material, which is consistent with recommendations documented by Dr. Kyle

33 Rollins (Remund 2017). We estimate that the compressive strength of the 35 pcf LDCC is 80 pounds per square inch  
34 (psi), or a cohesion of 40 psi. The compressive strength shall not exceed the 300-psi compressive strength of  
35 controlled density fill (CDF) to allow for excavation for utility maintenance.

## 36 **Seismic Design**

37 Based on the estimated bridge deformation provided by the structural engineer and the estimated wall deformation  
38 provided by the wall designer, we understand the structures are capable of sufficient movement under the  
39 Washington State Department of Transportation (WSDOT) hazard level using  $k_h = 0.6 * k_{h0}$ , where  $k_{h0}$  is the seismic  
40 horizontal coefficient assuming zero wall displacement, as provided in the Bridge 28 design report. The estimated  
41 structure deformation for this seismic hazard level is approximately 0.5 inch. Documentation of the estimated  
42 structure deformation analysis is provided in our Bridge 28 design report. Table 1 provides the horizontal  
43 acceleration coefficients that were used to calculate the seismic earth pressure coefficients.

44 **Table 1: Seismic Horizontal Acceleration Coefficient**

Hazard	$k_h = 0.5 * k_{h0}$	$k_h = 0.6 * k_{h0}$
Safety Evaluation Earthquake (SEE)/WSDOT	0.252	0.302 g

45 Notes:

- 46 a. Unless noted otherwise, all the seismic lateral earth pressure calculations were based on  $k_h = 0.6 * k_{h0}$ .  
47  $K_h = 0.5 * k_{h0}$  is provided as a reference value only.

## 48 **Low-Density Cellular Concrete Loading**

### 49 **Lateral Earth Pressure Parameters**

50 For abutments under seismic loading, lateral earth pressures shall be evaluated according to the diagrams and  
51 assumptions shown in Figure 6, per Section 11.6.5.1 of the American Association of State Highway and  
52 Transportation Officials (AASHTO) load resistance factored design (LRFD) Bridge Design Specifications.

53 For the bridge abutments addressed in this report, we assume the bridge is capable of sufficient movement under  
54 WSDOT seismic loading to allow for the use of  $k_h \leq 0.6 * k_{h0}$ , where  $k_{h0}$  is the seismic horizontal coefficient  
55 assuming negligible wall displacement. Table 2 provides horizontal acceleration coefficients that were used to  
56 calculate the seismic active and passive earth pressure coefficients. The static and seismic lateral earth pressure  
57 parameters acting on the bridge abutment are for static and seismic conditions with flat ground behind the abutment  
58 and an interface friction angle of  $2/3 * \phi$ , where  $\phi$  is the friction angle of the backfill material.

59 We calculated a minimum width (distance behind the pile cap) of the LDCC mass required to resist sliding,  
60 assuming the LDCC is bearing on Engineering Stratigraphic Unit (ESU) 3B or stronger. Section A1-A1' shows ESU  
61 4D may be encountered at the base of the LDCC near the back of the pile caps. ESU 4D would have a similar  
62 resistance to sliding as ESU 3B based using the site-specific friction angle of 35 degrees. The minimum required  
63 width is dependent on the cut slope of the retained soil behind the LDCC, hereafter referred to as the LDCC batter  
64 angle as shown in Attachment 1. We provide the minimum widths needed to avoid applying active loads to the pile  
65 cap or bridge for various specified batter angles of the LDCC in Figure 7. These widths were determined by  
66 calculating the minimum width required to resist the seismic active forces in sliding below the LDCC. Calculations  
67 and a discussion on the seismic active pressure and minimum LDCC widths to resist the active pressure in sliding  
68 are presented in Appendix A. Once cured, if the LDCC is not structurally connected to the pile cap and the bridge  
69 abutment can deform independently of the LDCC, it will not impose static or seismic active earth pressure loads on  
70 the pile cap if the minimum widths on Figure 7 are met or exceeded. However, if the minimum width requirement  
71 per Figure 7 is not met, then active earth pressures shall be applied to the back of the pile cap. The static active earth  
72 pressure coefficients were determined using Coulomb earth pressure methods, and the seismic active earth pressure  
73 coefficients were determined using Mononobe-Okabe methods. Active earth pressure coefficients are provided in  
74 Table 2.

75 Regardless of the LDCC width or batter angle, the bridge designer shall account for the static lateral earth pressure  
76 of each LDCC lift in the uncured condition. This shall be calculated using the cast density of the LDCC,  
77  $P_a = 40 \text{ pcf} * 0.5 * H^2 * K_a$ , where  $H$  is the height of the LDCC lift, and  $K_a = 1.0$ .

78 Log spiral methods and AASHTO Figures A11.4-2 were used to determine the static and seismic passive earth  
79 pressure coefficients for gravel borrow, respectively. The static and seismic passive earth pressure coefficients for  
80 ESU 3B were evaluated using general limit equilibrium methods in the program Slide2 (version 9.018) for an LDCC  
81 height of 10.5 feet, and are documented in Appendix A. If imported fill material is used as backfill behind the  
82 LDCC, WSDOT Gravel Borrow or stronger shall be used.

83 Passive pressures shall be calculated for the granular material behind the LDCC (i.e., native or imported fill  
84 material) per AASHTO LRFD Section 3.11.5.4 using the earth pressure coefficients provided in Table 2. If the  
85 LDCC is formed and cast without a batter (i.e., vertical face) against the native soil, the earth pressure coefficient  
86 and unit weight of ESU 3B shall be used to calculate the passive pressure. If the LDCC is formed and cast vertically  
87 and then backfilled with compacted gravel borrow, and the slope for the gravel borrow is shallower than a 1.5H:1V,  
88 the gravel borrow earth pressure coefficient and unit weight shall be used to calculate the passive resistance. If the  
89 LDCC is formed and cast vertically and then backfilled with compacted gravel borrow, and the slope for the gravel  
90 borrow is steeper than a 1.5H:1V, the earth pressure coefficient of ESU 3B shall be used in conjunction with the unit  
91 weight of ESU 3B when calculating the passive resistance. If the LDCC is placed directly against a slope (i.e.,  
92 battered), the unit weight of the LDCC shall be used to calculate the passive resistance in combination with the earth  
93 pressure coefficient for ESU 3B.

94 The earth pressure loads and resistances throughout this report do not include load or resistance factors. Resistance  
95 factors are provided in Table 3, determined per AASHTO Section 11.5.7.

96 **Table 2: LDCC – Lateral Earth Pressure Coefficients (Flat Backslope)**

Backfill Material Type	$k_h$	Static Loading		Seismic Loading	
		$K_A$	$K_P$	$K_{AE}$	$K_{PE}$
ESU 3B	0.252g	0.254	5.701	0.448	5.572
Gravel Borrow		0.217	10.387	0.394	7.500
ESU 3B	0.302g	0.254	5.701	0.504	5.183
Gravel Borrow		0.217	10.387	0.444	7.750

97 Notes:

- 98 a. A sliding resistance component may be incorporated for the horizontal length at the base of the LDCC mass and  
99 shall be calculated per AASHTO Section 10.6.3.4. If incorporated, the total passive resistance would be the  
100 passive lateral earth pressure plus the sliding resistance along the base of the LDCC. Alternatively, the sliding  
101 resistance may be neglected. If the sliding resistance is incorporated, assume a friction angle of 34 degrees for  
102 ESU 3B, a unit weight of 35 pcf for LDCC to determine the vertical force, and C shall be taken as 1.0 for equation  
103 10.6.3.4-2 of AASHTO.
- 104 b. If minimum widths are met per Figure 7, active earth pressures do not need to be applied. If the minimum width  
105 is not met, active earth pressures shall be applied to the back of the LDCC.
- 106 c. If the LDCC back face is formed vertically and backfilled against, gravel borrow parameters shall be used or the  
107 presumptive passive pressure may be calculated per Bridge Design Manual (BDM) Section 5.2.2. If the LDCC is  
108 poured against the native material, as shown in Figures A-1 to A-3, ESU 3B parameters shall be used.

109 **Table 3: Resistance Factors for Abutment Walls**

Limit State	Resistance Factor, $\phi$		
	Bearing	Shear Resistance to Sliding	Passive Pressure Resistance to Sliding
Strength	0.55	1.0	0.5
Service	1.0	1.0	1.0
Extreme	0.8	1.0	1.0

110

111 The lateral inertial force imposed on the soldier pile wall due to the LDCC dead load surcharge behind the bridge  
112 abutment ( $W_{\text{surcharge}}$ ) due to seismic earth pressure loading from the LDCC,  $K_h W_{\text{surcharge}}$ , shall be applied to the  
113 soldier pile wall per AASHTO Figure 11.6.5.1-1. The LDCC dead load surcharge,  $W_{\text{surcharge}}$ , shall be calculated per  
114 AASHTO LRFD Figure 11.10.7.1-1 (a), where the surcharge load width is  $0.5H$  and  $H$  is the height of the LDCC as  
115 shown in Attachment 1. This assumes the LDCC mass acts similarly to a Mechanically Stabilized Earth (MSE) wall  
116 behind the pile cap.

117 Use AASHTO LRFD Table C3.11.1-1 to estimate the relative displacement of the pile cap required to reach the  
118 active or passive pressure condition. Since the passive pressure is controlled by mobilization of the retained soil  
119 behind the LDCC, we recommend using the “medium dense sand” for ESU 3B backfill type. This corresponds to a  
120  $\Delta/H$  value of 0.002 for active conditions and 0.02 for passive conditions, where  $H$  is the height of the pile cap at  
121 each bridge abutment. If the retained soil behind the LDCC is backfilled with dense granular material, then a value  
122 of 0.001 for  $\Delta/H$  for active conditions and a value 0.01 for passive conditions for “dense sand” may be used.

123 If accounted for, the sliding component may be assumed to be fully mobilized at 0.25 inch, which is consistent with  
124 AASHTO Section C10.6.3.4 saying that the sliding component is mobilized over a very small deformation.

## 125 **Global Slope Stability and Soil Settlement**

126 Due to its lower unit weight, the excavation and replacement of existing soil with LDCC behind the BR 28E pile  
127 caps reduces the overburden pressure on the soil behind the walls and the surcharge load applied to the walls.  
128 Therefore, by observation, use of LDCC as backfill behind the pile caps will not adversely affect our original global  
129 slope stability analyses of the walls or increase our estimated soil settlement at the bridge abutments. The  
130 differential settlement between the bridge abutment and the LDCC behind the abutment should also be reduced due  
131 to the reduction in the surcharge load where the LDCC is placed. See the Bridge 28 design report for the original  
132 global stability analyses of walls MR-O and GR-O, as well as the estimated settlement at each bridge abutment.

133 We do not anticipate any significant impacts on the Bridge 28W abutment wall or ML-O walls from the addition of  
134 the LDCC. As described above and depending on the final width/batter angle of the LDCC, the LDCC may reduce  
135 the surcharge load estimated for the Bridge 28W-E abutment wall, and may reduce the estimated settlement behind  
136 the abutment wall. If the LDCC extends laterally beyond the Bridge 28E-W pile cap, the lateral earth pressures on  
137 the ML-O walls would also be reduced. This would also result in having a stronger, lighter material at the ground  
138 surface behind the ML-O walls, which would improve the slope stability. Therefore, it is conservative to keep the  
139 ML-O wall design the same (i.e., assuming full height traditional backfill material).

## 140 **Construction Considerations**

### 141 **Cellular Concrete**

142 Cellular concrete shall be produced, placed, and tested in accordance with Caltrans Pavement Plans and  
143 Specifications Chapter 4-9006 and Elastizell Corporation of America sampling and testing recommendations  
144 (Elastizell 2021). These recommendations include, but are not limited to, the following:

- 145           • Cellular concrete material properties are largely dependent on cast density. Our lateral earth pressure  
146           recommendations are also dependent on cast density. We recommend that the cellular concrete density  
147           be measured at regular and frequent intervals, at the point of placement, throughout the placement  
148           process. A set of four cylinders shall be cast for at least every 100 cubic yards of fill placed. Cylinders  
149           shall be representative of the material placed. Additional cylinders may need to be cast if cylinders are  
150           not considered representative due to changes made during the placement process. The unconfined  
151           compressive strength (UCS) of the cylinders shall be tested after 28 days of curing. The UCS of the  
152           cylinder shall be defined as the peak strength or the UCS reached at 1 percent strain (whichever comes  
153           first). Additional UCS tests may be taken with less curing time to see if 28-day cylinders will meet  
154           minimum requirements.
- 155           • Cellular concrete shall be placed in lifts no greater than 3 feet. Concrete shall be given at least 12 hours  
156           to cure before the next lift is placed. Care must be taken to ensure the cellular concrete surface is clean  
157           to create a good bonding surface for the next lift. Loose concrete may also need to be removed to  
158           create a better bonding surface. Concrete shall not be placed in standing water and shall not be placed  
159           on frozen ground.
- 160           • Cellular concrete generally cures faster than typical concrete. For this reason, it is important that a  
161           single lift of concrete be continuously placed. Delays during concrete placement may adversely affect  
162           the strength and density of the concrete.

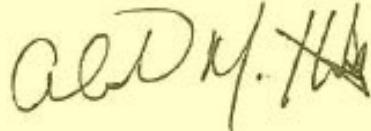
163           **Other Utilities**

164           We understand that per City of Renton requirements, the water line that will be installed within the new Bridge 28  
165           and extend out through the cellular concrete will need to be surrounded by at least 1 foot of pipe bedding material.  
166           Material shall meet the specifications of WSDOT Standard Specifications Section 9-03.12(3) Gravel Backfill for  
167           Pipe Zone Bedding.

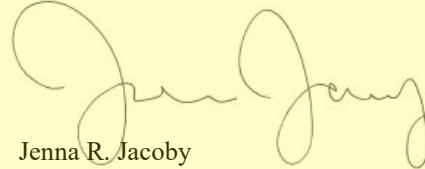
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December 20, 2021  
Page 6 of 10

168 Please feel free to contact us if you have any questions concerning this report.

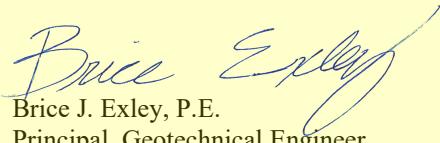
169 Sincerely,



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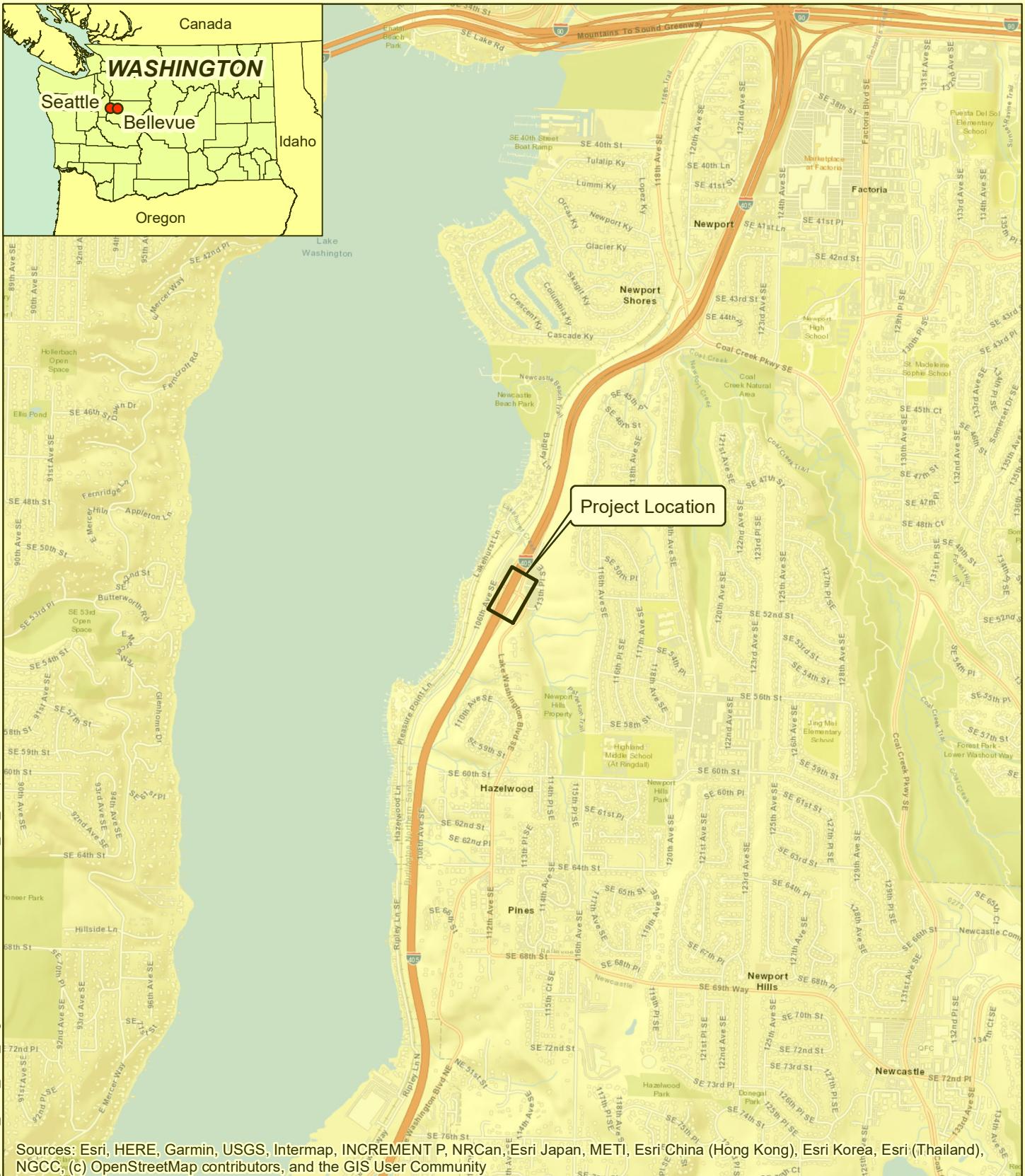
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**Attachments:**

- 171 Figure 1 – Vicinity Map  
172 Figure 2 – Site and Exploration Plan  
173 Figure 3 – Generalized Subsurface Profile A1-A1'  
174 Figure 4 – Generalized Subsurface Profile A2-A2'  
175 Figure 5 – Generalized Subsurface Profile A3-A3'  
176 Figure 6 – Lateral Earth Pressures on Conventional Walls  
177 Figure 7 – Required LDCC Batter for Select Minimum LDCC Widths  
178 Attachment 1 – Bridge 28E Structural Plans  
179 Appendix A – Calculation Package  
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183 JRJ/AH/BJE/MES  
184 \\haleyaldrich.com\\share\\sea\_projects\\notebooks\\1943404\_wsdot\_i-405\_staff\_augmentation\\deliverables in-basket\\bridge 28 east  
185 ldcc\_rfu\\2021\_1220\_bridge28east\_ldccbackfillrfu\_f.docx

186 **References**

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Feet

Note: Feature locations are approximate.



### I-405 Renton to Bellevue Express Toll Lanes Bellevue, Washington

#### Vicinity Map

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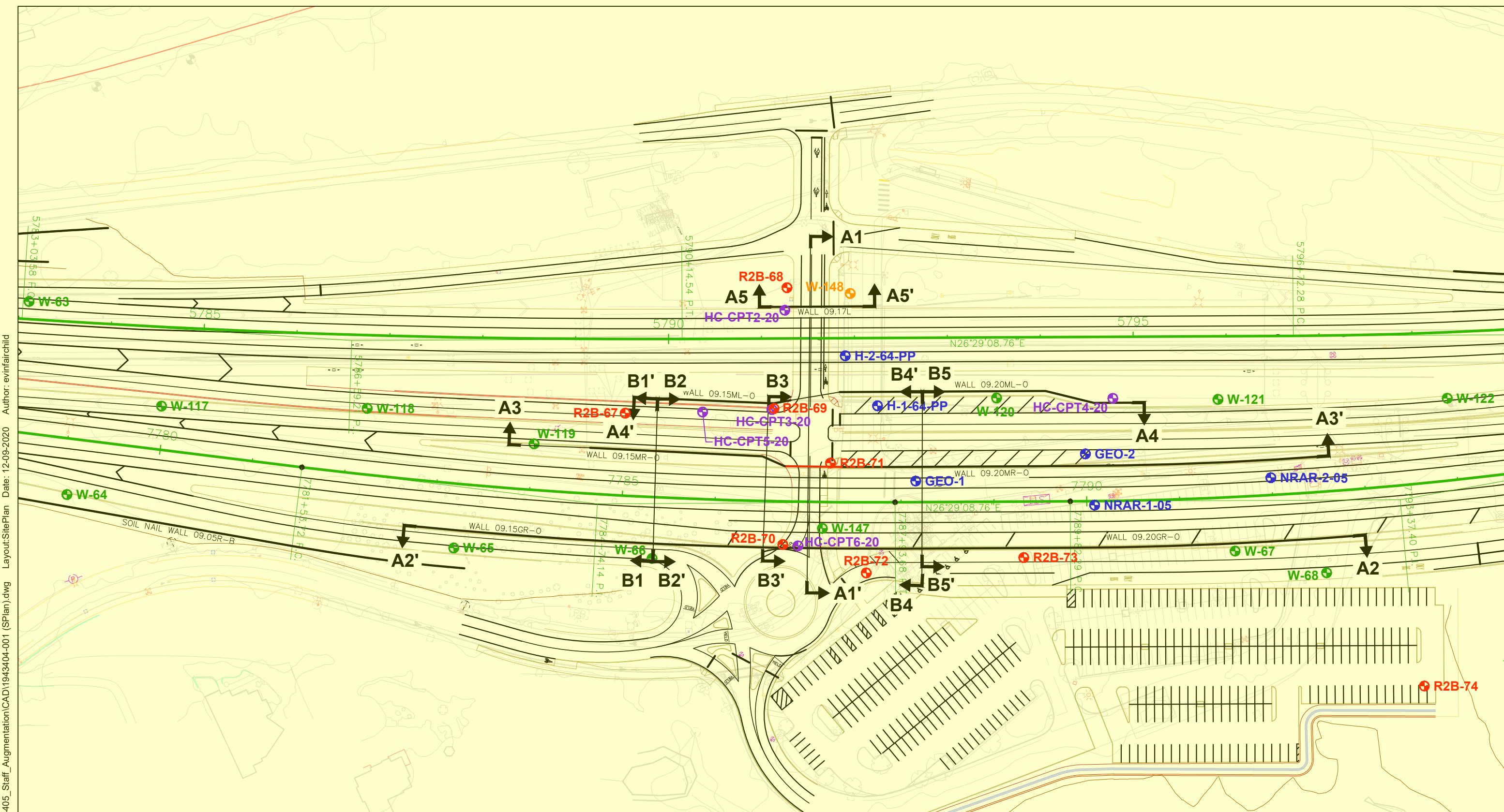
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A division of Haley & Aldrich

**wood.**  
**LANE**

**FLATIRON**

Figure

1



I-405 Renton to Bellevue Express Toll Lanes  
Bellevue, Washington

**Site and Exploration Plan**

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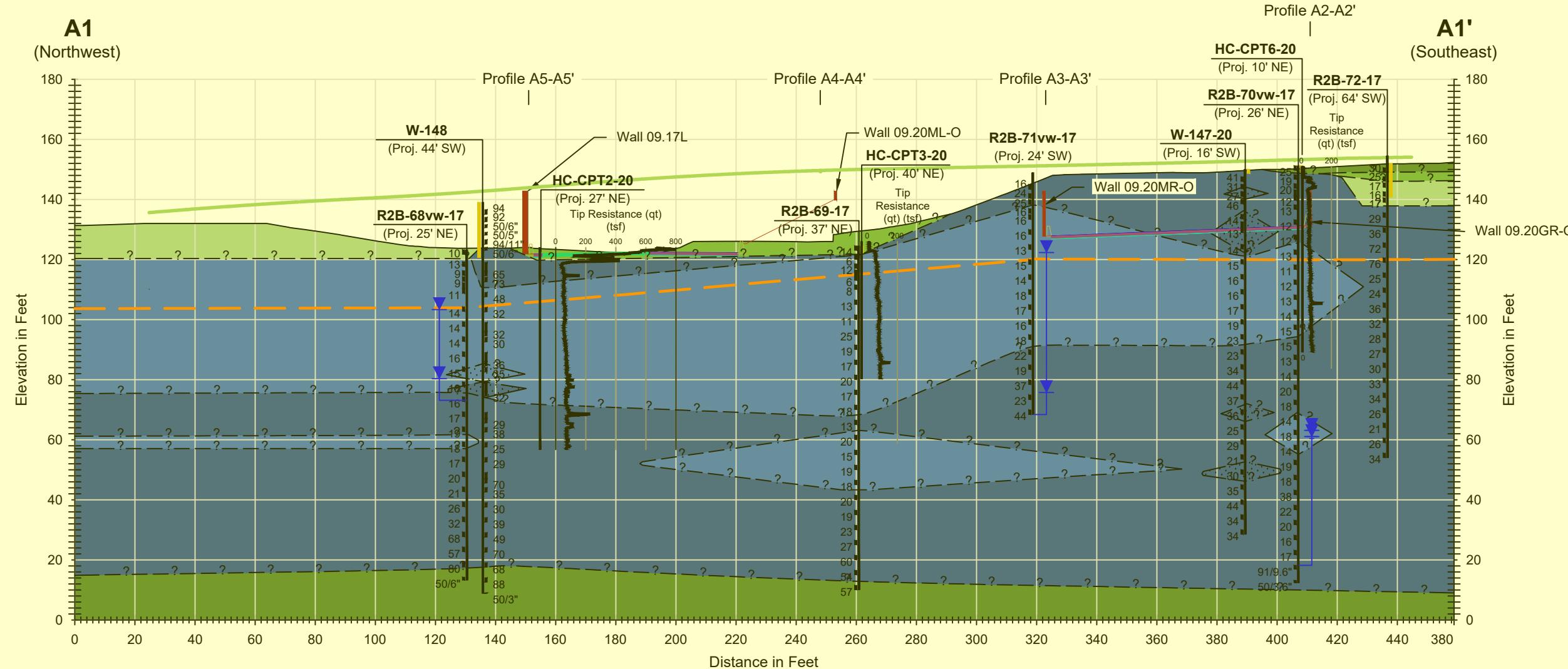
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**HARTCROWSER**  
A Division of Hilti Aldrich

**WOOD.**  
FLATIRON LANE

Figure  
**2**

0 100 200  
Scale in Feet



### Legend

Boring Name with Offset	W-148
Boring Location	SM — Soil Classification
Possible Fill	■ — Water Level
N-Value	— Estimated Water Level
	— Water Level with Piezometer
	▼ — Perched Water
	— Retaining Wall
	— Top of Roadway

ESU 1 - Project Fill (new)
ESU 2A - Peat
ESU 2B - Granular with organics
ESU 2C - Fines with organics or organic fines
ESU 3A - Loose granular
ESU 3B - Med dense granular
ESU 3C - Dense granular
ESU 3D - Very dense granular
ESU 4A - Soft to medium stiff fines
ESU 4B.1 - Medium stiff to stiff fines (high plasticity)
ESU 4B.2 - Medium stiff to stiff fines (low plasticity)
ESU 4C - Very stiff to hard fines - intact (high plasticity)
ESU 4D - Very stiff to hard fines - intact (low plasticity)
ESU 4E - Very stiff to hard fines - disturbed (high plasticity)
ESU 4F - Very stiff to hard fines - disturbed (low plasticity)
ESU 5A - Landslide deposits - granular
ESU 5B - Landslide deposits - fines

### Notes:

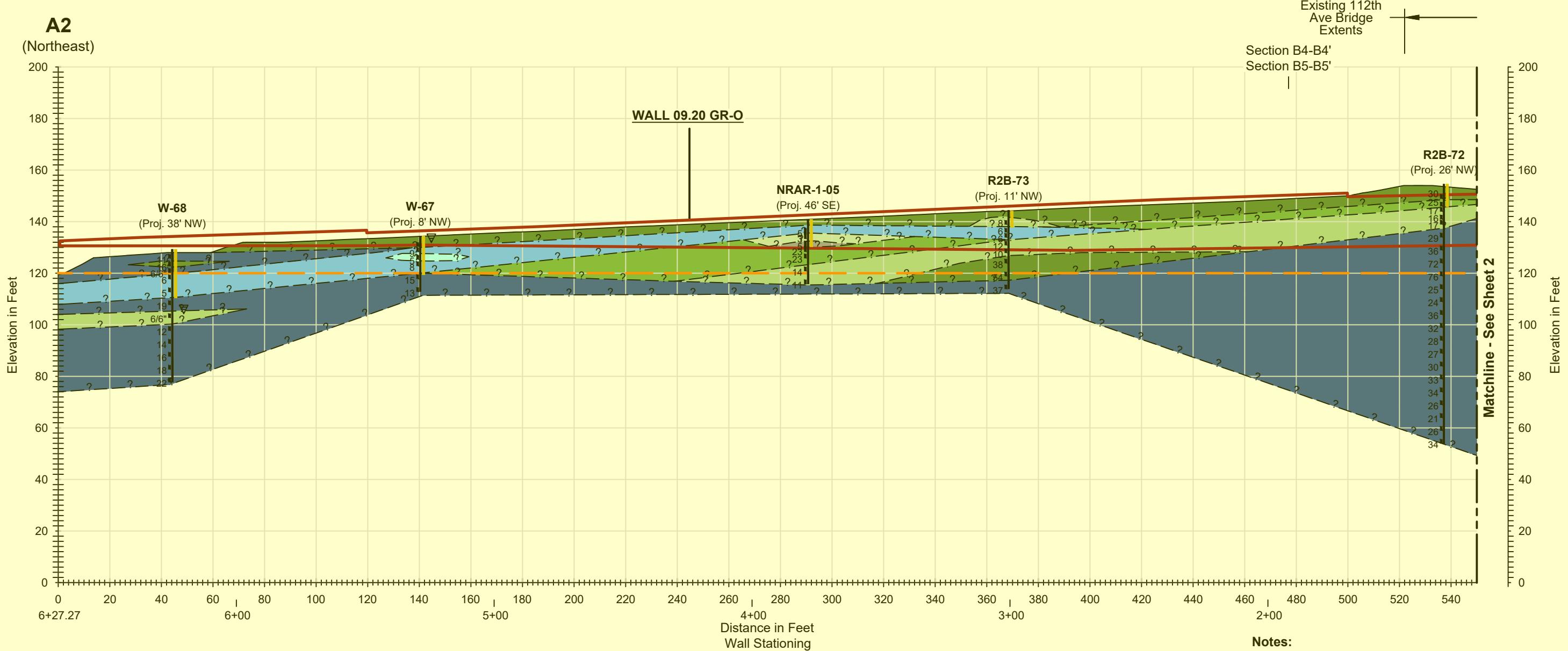
- 1) ESU definitions based on N160 value. Sections show raw N-value.
- 2) Subsurface conditions are interpreted from explorations at discrete locations. Layer contacts are estimates only.

0 40 80  
Horizontal and Vertical Scale in Feet

I-405 Renton to Bellevue Express Toll Lanes  
Bellevue, Washington

### Generalized Subsurface Section A1-A1'

19434-04 05/21



- Notes:**
- 1) ESU definitions based on N160 value. Sections show raw N-value.
  - 2) Subsurface conditions are interpreted from explorations at discrete locations. Layer contacts are estimates only.

#### Legend

Boring Name	<b>W-148</b>	ESU 1 - Project Fill (new)
with Offset	— (Proj. 57' SW)	ESU 2A - Peat
Boring Location	SM — Soil Classification	ESU 2B - Granular with organics
Possible Fill	▼ — Water Level	ESU 2C - Fines with organics or organic fines
N-Value	— Estimated Water Level	ESU 3A - Loose granular
	— Water Level with Piezometer	ESU 3B - Med dense granular
	▼ — Perched Water	ESU 3C - Dense granular
		ESU 3D - Very dense granular
		ESU 4A - Soft to medium stiff fines
		ESU 4B.1 - Medium stiff to stiff fines (high plasticity)
		ESU 4B.2 - Medium stiff to stiff fines (low plasticity)
		ESU 4C - Very stiff to hard fines - intact (high plasticity)
		ESU 4D - Very stiff to hard fines - intact (low plasticity)
		ESU 4E - Very stiff to hard fines - disturbed (high plasticity)
		ESU 4F - Very stiff to hard fines - disturbed (low plasticity)
		ESU 5A - Landslide deposits - granular
		ESU 5B - Landslide deposits - fines

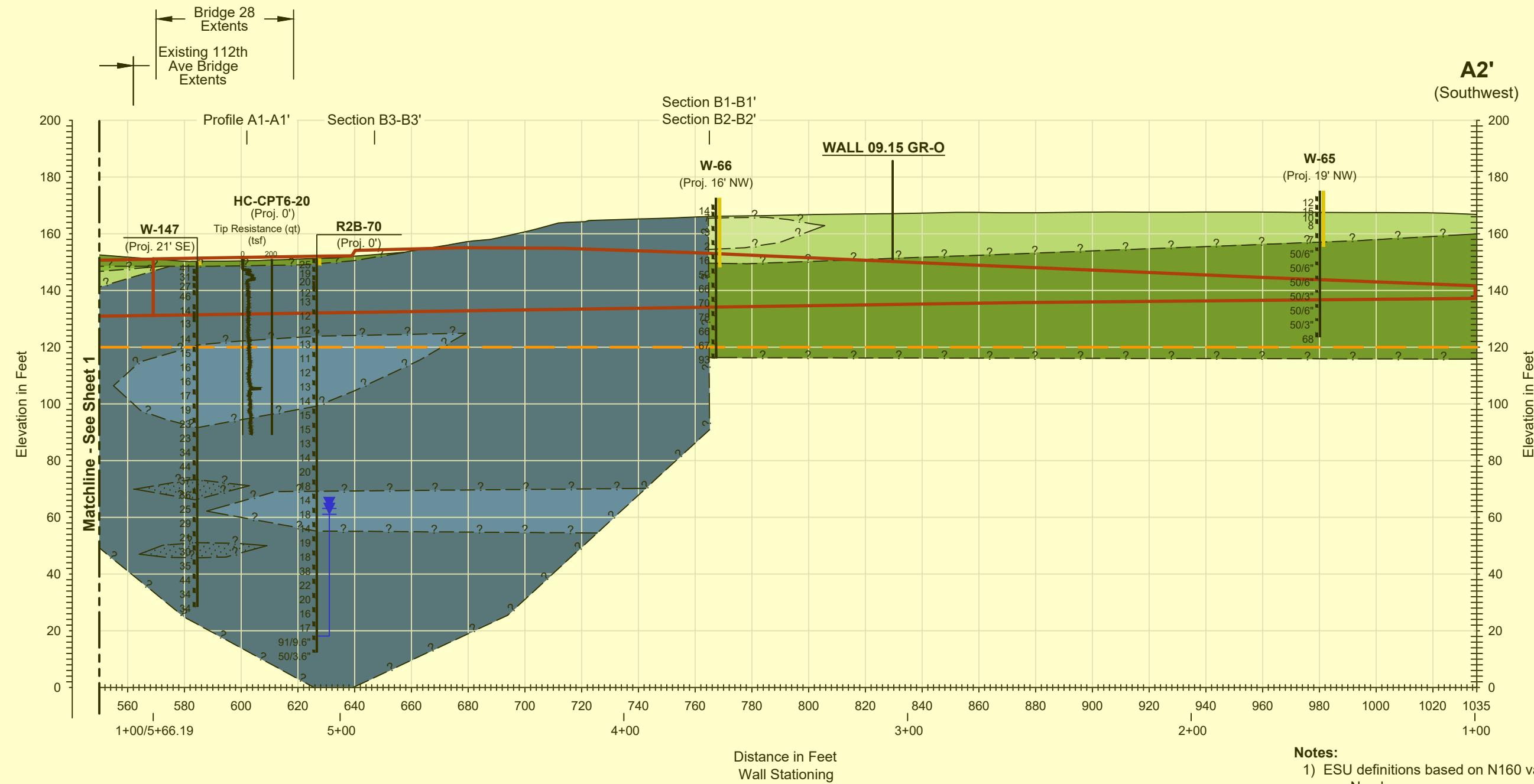
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Horizontal and Vertical Scale in Feet		

I-405 Renton to Bellevue Express Toll Lanes  
Bellevue, Washington

**Generalized Subsurface Profile A2-A2'**  
Sheet 1 of 2

19434-04

12/20

**Legend**

- Boring Name **W-148**  
with Offset — (Proj. 57' SW)
- Boring Location — SM — Soil Classification
- Possible Fill — □ — Water Level
- N-Value — 22 — Estimated Water Level
- Water Level with Piezometer
- Perched Water

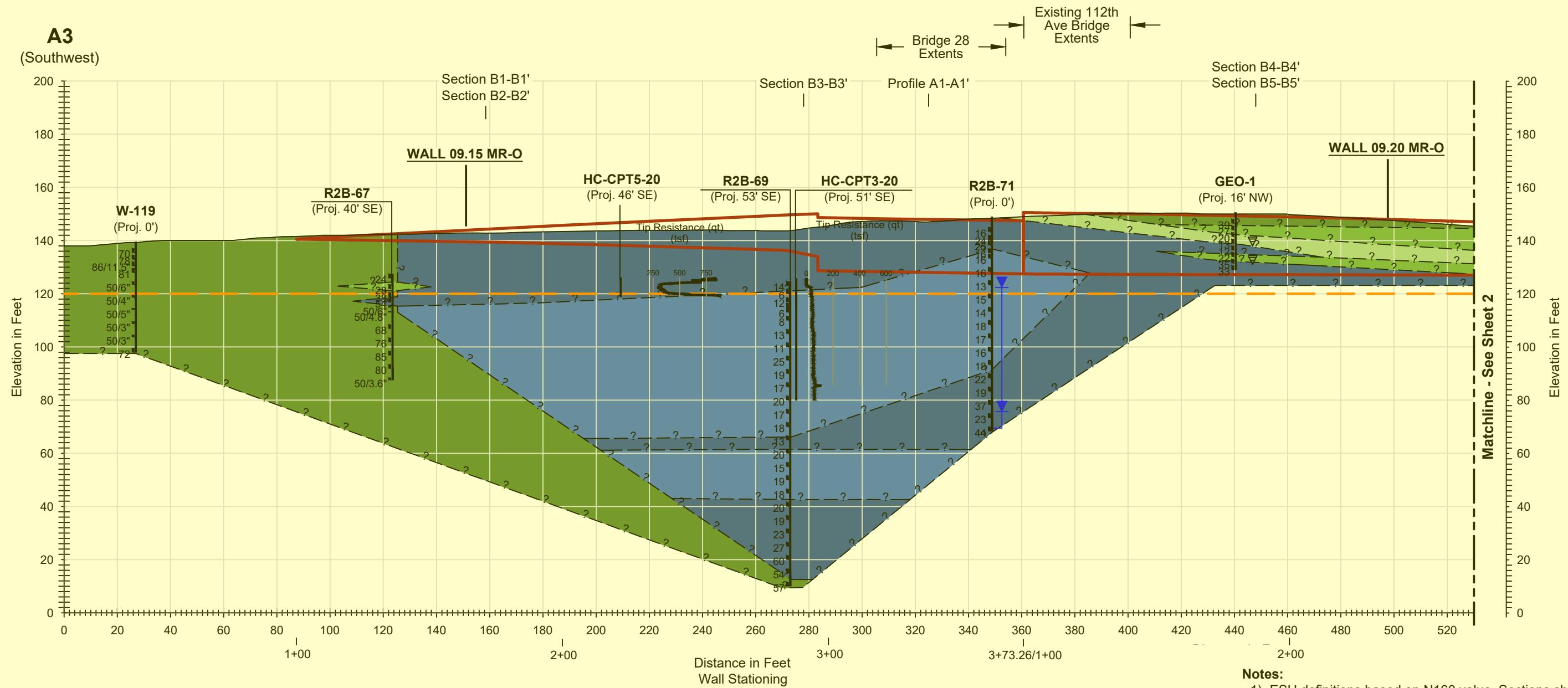
- ESU 1 - Project Fill (new)
- ESU 2A - Peat
- ESU 2B - Granular with organics
- ESU 2C - Fines with organics or organic fines
- ESU 3A - Loose granular
- ESU 3B - Med dense granular
- ESU 3C - Dense granular
- ESU 3D - Very dense granular
- ESU 4A - Soft to medium stiff fines

- ESU 4B.1 - Medium stiff to stiff fines (high plasticity)
- ESU 4B.2 - Medium stiff to stiff fines (low plasticity)
- ESU 4C - Very stiff to hard fines - intact (high plasticity)
- ESU 4D - Very stiff to hard fines - intact (low plasticity)
- ESU 4E - Very stiff to hard fines - disturbed (high plasticity)
- ESU 4F - Very stiff to hard fines - disturbed (low plasticity)
- ESU 5A - Landslide deposits - granular
- ESU 5B - Landslide deposits - fines

0 40 80  
Horizontal and Vertical Scale in Feet

I-405 Renton to Bellevue Express Toll Lanes  
Bellevue, Washington

Generalized Subsurface Profile A2-A2'  
Sheet 2 of 2  
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- Notes:**
- 1) ESU definitions based on N160 value. Sections show raw N-value.
  - 2) Subsurface conditions are interpreted from explorations at discrete locations. Layer contacts are estimates only.

#### Legend

- Boring Name **W-148**  
with Offset — (Proj. 57' SW)
- Boring Location — SM — Soil Classification  
— ▼ — Water Level
- Possible Fill — ■ — Estimated Water Level  
— — Water Level with Piezometer
- N-Value — 22 — Perched Water

- ESU 1 - Project Fill (new)
- ESU 2A - Peat
- ESU 2B - Granular with organics
- ESU 2C - Fines with organics or organic fines
- ESU 3A - Loose granular
- ESU 3B - Med dense granular
- ESU 3C - Dense granular
- ESU 3D - Very dense granular
- ESU 4A - Soft to medium stiff fines

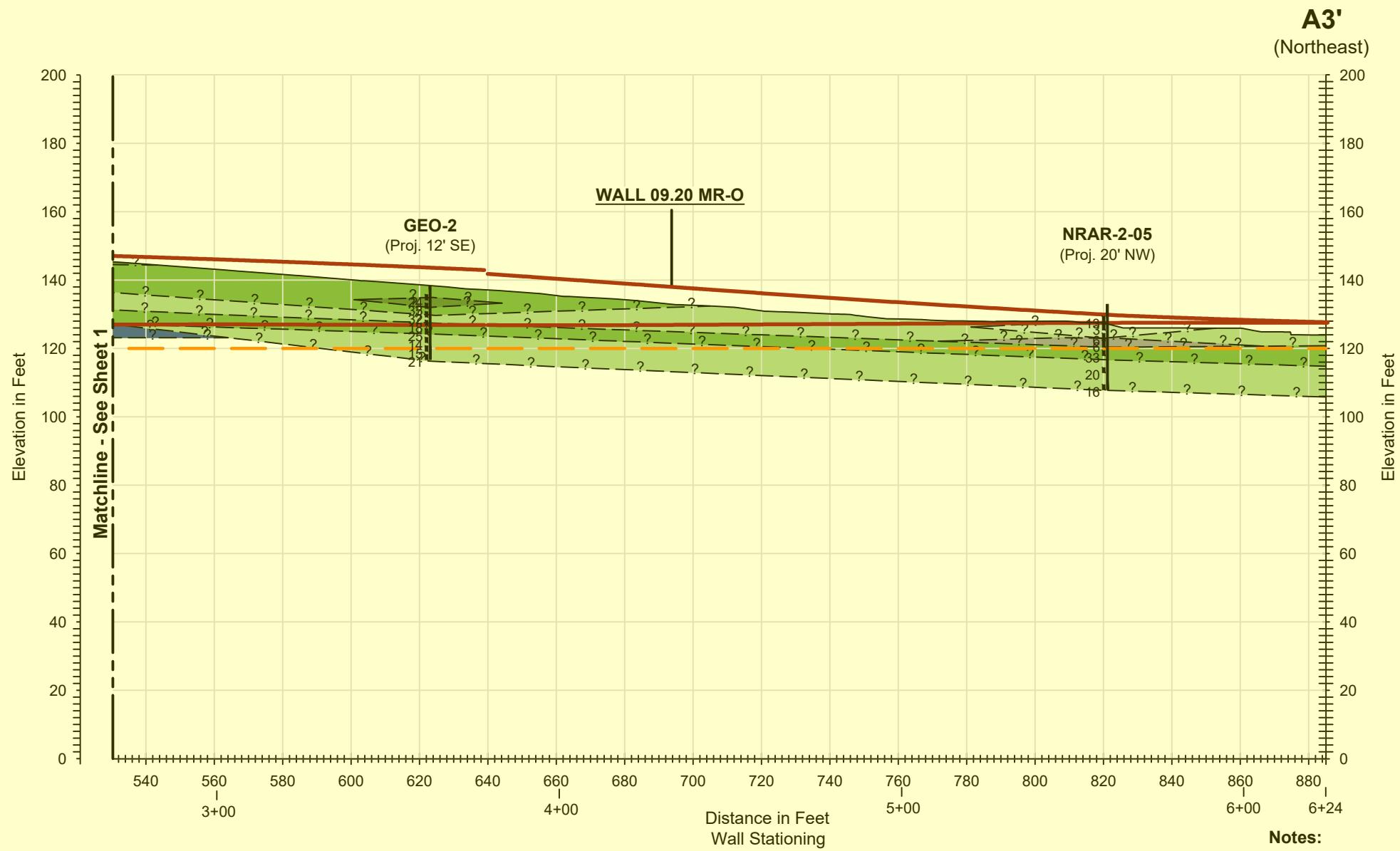
- ESU 4B.1 - Medium stiff to stiff fines (high plasticity)
- ESU 4B.2 - Medium stiff to stiff fines (low plasticity)
- ESU 4C - Very stiff to hard fines - intact (high plasticity)
- ESU 4D - Very stiff to hard fines - intact (low plasticity)
- ESU 4E - Very stiff to hard fines - disturbed (high plasticity)
- ESU 4F - Very stiff to hard fines - disturbed (low plasticity)
- ESU 5A - Landslide deposits - granular
- ESU 5B - Landslide deposits - fines

0 40 80  
Horizontal and Vertical Scale in Feet

I-405 Renton to Bellevue Express Toll Lanes  
Bellevue, Washington

Generalized Subsurface Profile A3-A3'  
Sheet 1 of 2

19434-04 12/20



#### Legend

- Boring Name **W-148**  
with Offset — (Proj. 57' SW)
- Boring Location — SM — Soil Classification
- Possible Fill — □ — Water Level
- N-Value — 22 — Estimated Water Level
- N-Value — 22 — Water Level with Piezometer
- N-Value — ▽ — Perched Water

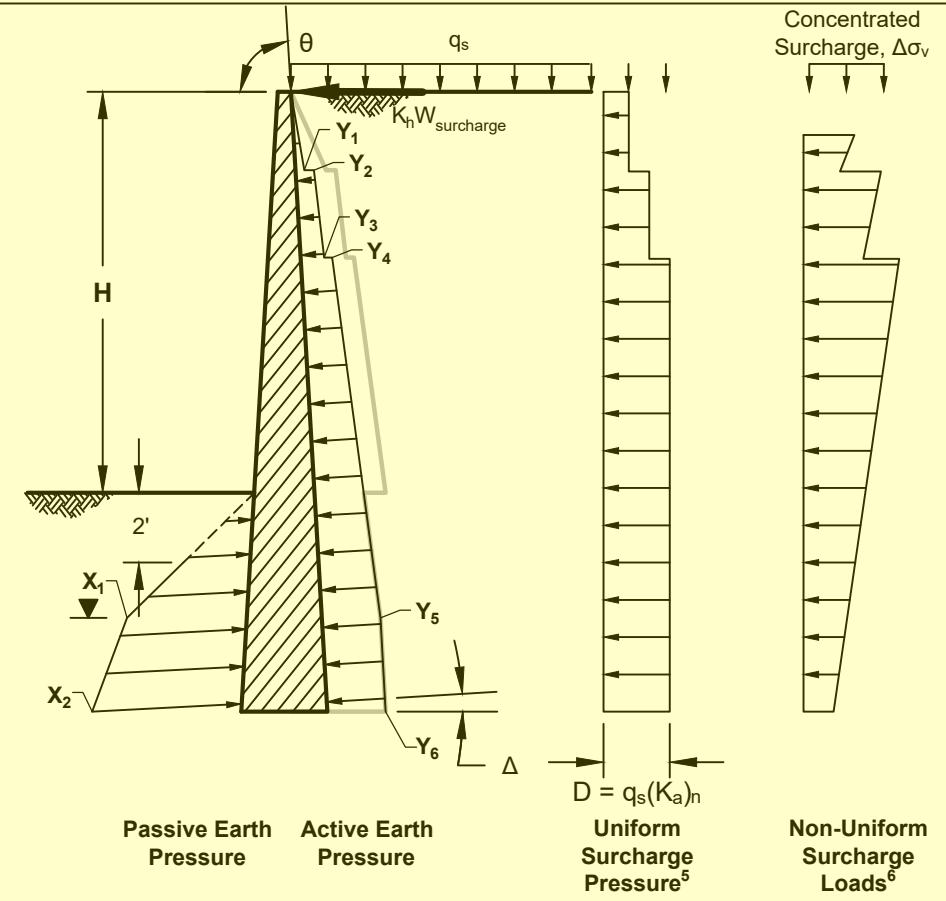
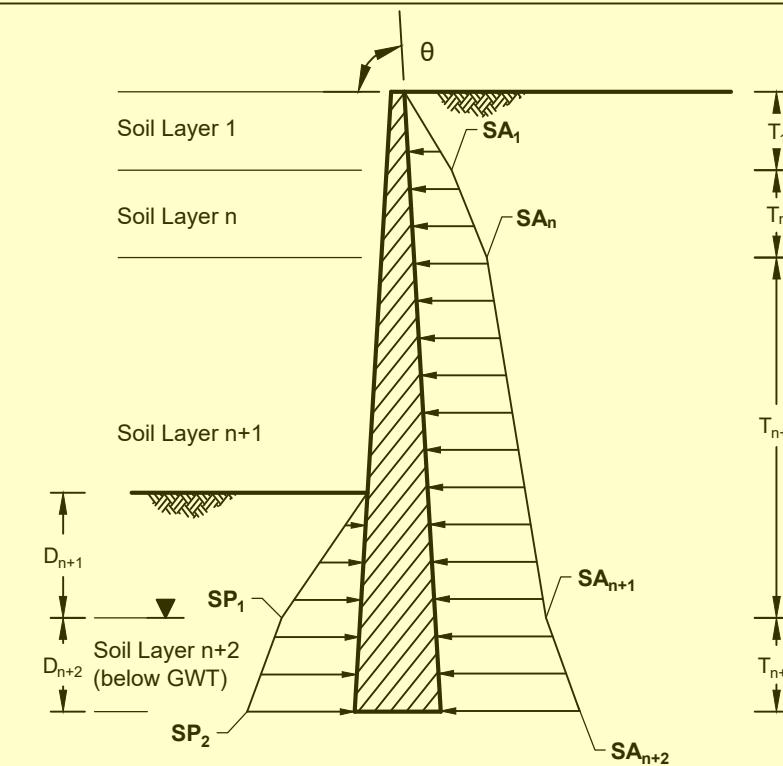
ESU 1 - Project Fill (new)	ESU 4B.1 - Medium stiff to stiff fines (high plasticity)
ESU 2A - Peat	ESU 4B.2 - Medium stiff to stiff fines (low plasticity)
ESU 2B - Granular with organics	ESU 4C - Very stiff to hard fines - intact (high plasticity)
ESU 2C - Fines with organics or organic fines	ESU 4D - Very stiff to hard fines - intact (low plasticity)
ESU 3A - Loose granular	ESU 4E - Very stiff to hard fines - disturbed (high plasticity)
ESU 3B - Med dense granular	ESU 4F - Very stiff to hard fines - disturbed (low plasticity)
ESU 3C - Dense granular	ESU 5A - Landslide deposits - granular
ESU 3D - Very dense granular	ESU 5B - Landslide deposits - fines
ESU 4A - Soft to medium stiff fines	

I-405 Renton to Bellevue Express Toll Lanes  
Bellevue, Washington

Generalized Subsurface Profile A3-A3'  
Sheet 2 of 2

19434-04

12/20



## Conventional Retaining Wall

Generalized Effective Stress Profile	
Active or At-Rest	$SA_1 \quad \gamma'_1 * T_1$
	$SA_n \quad SA_1 + \gamma'_n * T_n$
	$SA_{n+1} \quad SA_n + \gamma'_{n+1} * T_{n+1}$
	$SA_{n+2} \quad SA_{n+1} + \gamma'_{n+2} * T_{n+2}$
Passive	$SP_1 \quad \gamma'_{n+1} * D_{n+1}$
	$SP_2 \quad SP_1 + \gamma'_{n+2} * D_{n+2}$

Nominal Lateral Earth Pressures (PSF)		
Active or At-Rest	$Y_1 \quad SA_1 * K_{a1}$	
	$Y_2 \quad SA_1 * K_{an}$	
	$Y_3 \quad SA_n * K_{an}$	
	$Y_4 \quad SA_n * K_{an+1}$	
	$Y_5 \quad SA_{n+1} * K_{an+1}$	
	$Y_6 \quad X_1 + SP_n * K_{an+2}$	
Passive	$X_1 \quad X_1 + SP_n * K_{pn+2}$	
	$X_2 \quad X_1 + SP_n * K_{pn+2}$	

### Notes:

- All earth pressures are in units of pounds per square foot.
- In absence of specific surcharge ( $q_s$ ), we recommend 250 psf ( $q_s$ ) be applied as a general construction surcharge.  $q_s$  assumes a uniformly distributed surcharge (AASHTO 3.11.6.1) within one half of the wall height, and as described in 3.11.6.4. The 250 psf construction surcharge is not prescriptive, and does not include other surcharges such as site specific soil surcharges.
- Non-uniform or concentrated surcharges which are not applied uniformly within one half of the wall height shall be calculated per AASHTO LRFD Section 3.11.6.2, 3.11.6.3, or attached surcharge distribution diagram if included. Diagram is conceptual only. Actual distribution would be per AASHTO sections referenced.
- Additional surcharge from footings, large stockpiles, heavy equipment, etc., must be added to these pressures.
- All dimensions are in feet.
- Diagrams are not to scale.
- $K_h W_{surcharge}$  is the portion of the lateral load associated with a surcharge located within the active wedge which is not resisted by an external structure as stiff or stiffer than the wall. This structure may be a bridge deck. Values of  $K_h$  can be found in the report text. Only incorporate this load under seismic conditions.
- Refer to the report for design groundwater elevations.
- See report text for values of  $K_a$ ,  $K_o$ ,  $K_p$  and  $\gamma'_n$ . Replace  $K_a$  with  $K_{ae}$  and  $K_p$  for  $K_{pe}$  under seismic loading.  $K_{ae}$  is only applicable above design grade for all conditions. Seismic loading is not applicable for temporary loading conditions. If the wall is embedded less than 5 feet, use  $K_p$  during seismic loading.
- Neglect the upper 2 feet of soil for passive resistance unless noted otherwise. Do not neglect upper 2 feet in seismic loading.
- Earth pressure diagrams are not intended for short term loading in fine-grained soils (undrained loading).

### Legend

- $\gamma'_n$ : Effective Unit Weight of Soil Layer  $n$
- $T$ : Thickness of Soil Layer  $n$  on Active Side of Pile
- $D_n$ : Thickness of Soil Layer  $n$  on Passive Side of Pile
- $SA_n$ : Vertical Effective Stress at Location of Interest on Active Side of Pile
- $SP_n$ : Vertical Effective Stress at Location of Interest on Passive Side of Pile
- $(K_x)_n$ : Lateral earth pressure coefficient for layer of interest
- $X_n, Y_n$ : Lateral earth pressure at depth  $n$
- $H$ : Total Height of Excavation, Feet
- : No-Load Zone
- : Seismic Earth Pressure Distribution (Per Note 9)
- ▽: Groundwater Table (GWT)

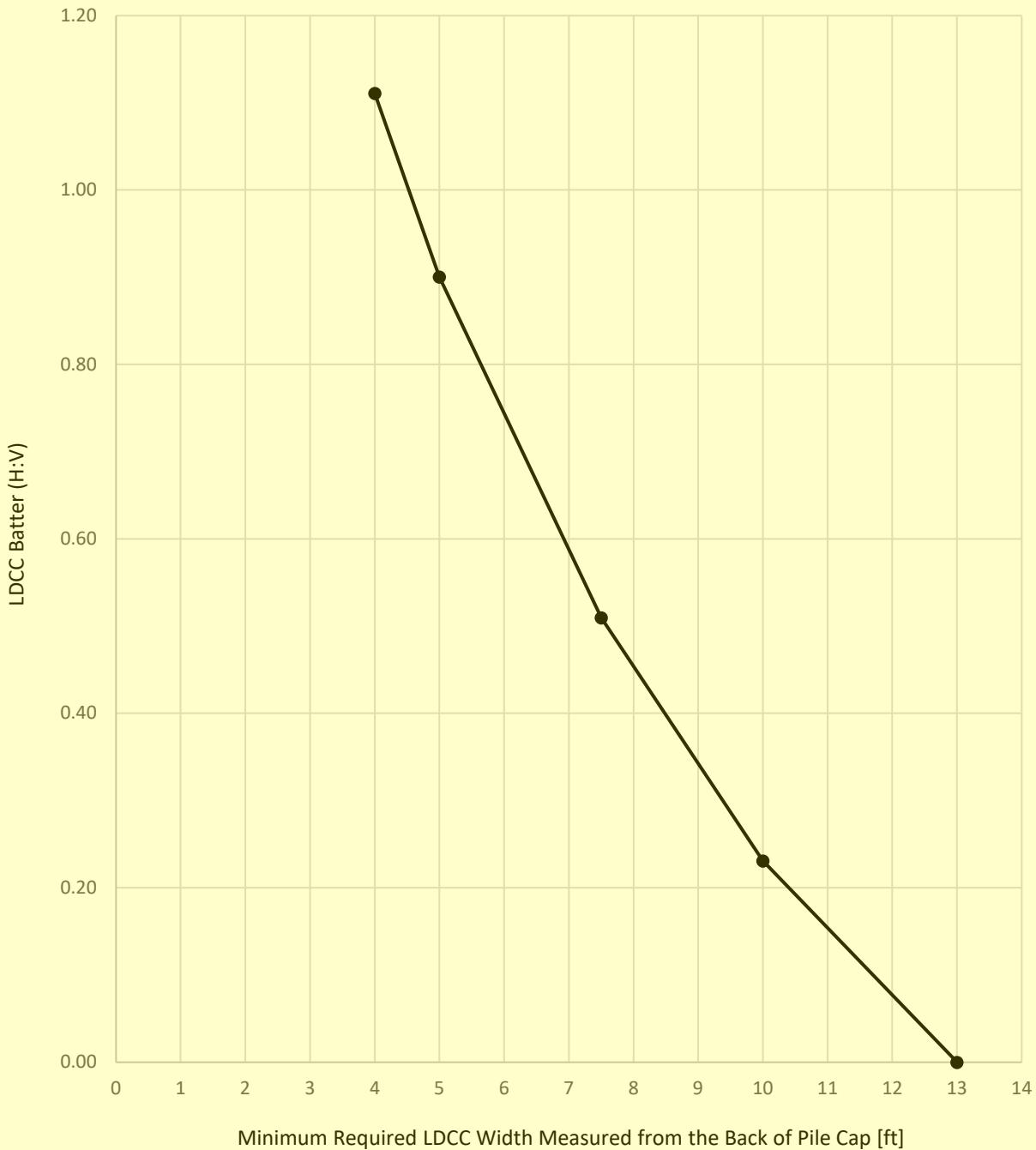
Not to Scale

I-405 Renton to Bellevue Express Toll Lanes  
Bellevue, Washington

### Lateral Earth Pressures on Conventional Walls

19434-04

06/21



I-405 Renton to Bellevue Express Toll Lanes  
Bellevue, Washington

**Required LDCC Batter for Select Minimum LDCC Widths**

19434-04

18-Aug

**HARTCROWSER**  
A division of Haley & Aldrich

Figure  
**7**

**FLATIRON**

**LANE** 

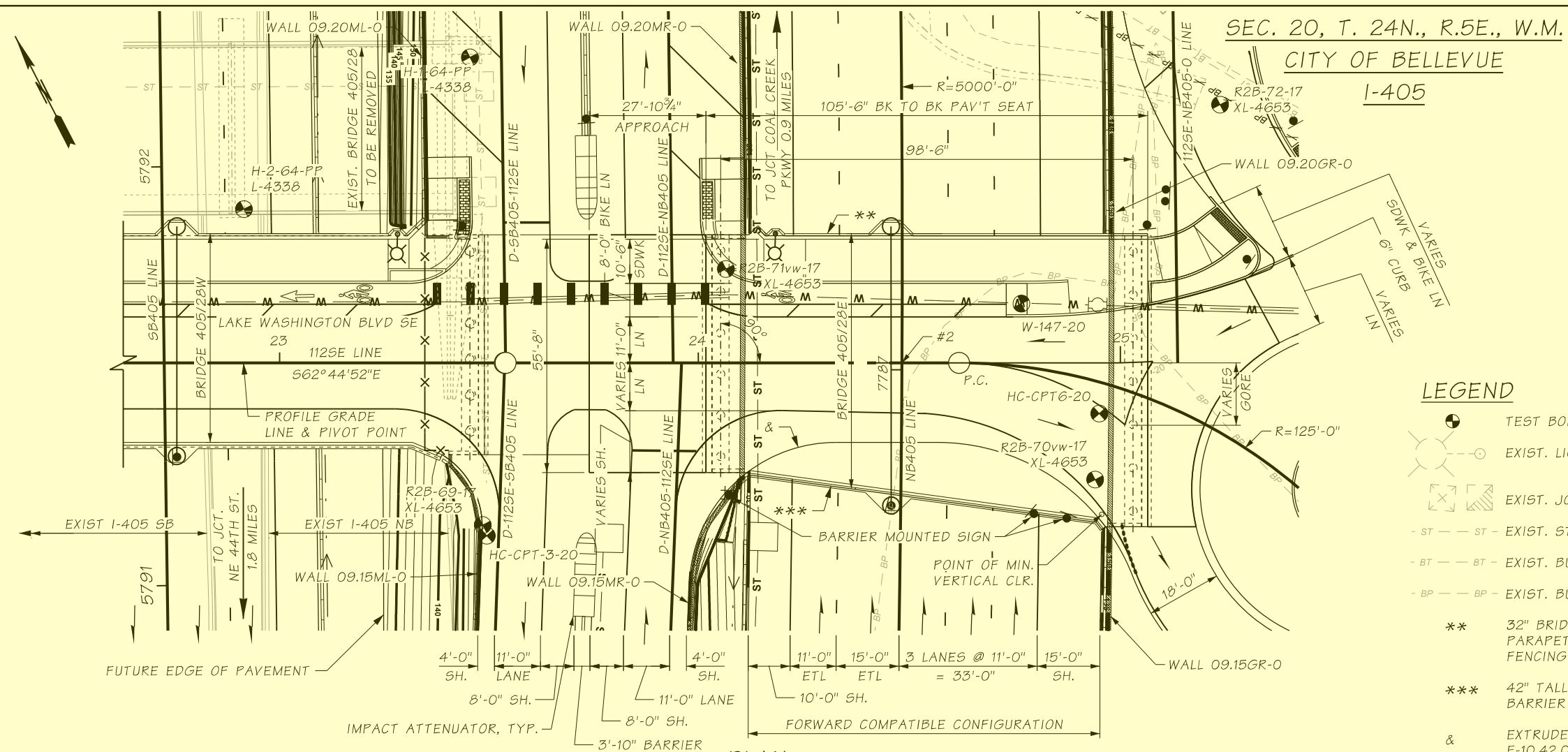
**wood.**

In Association with

**Attachment 1  
Bridge 28E Structural Plans**

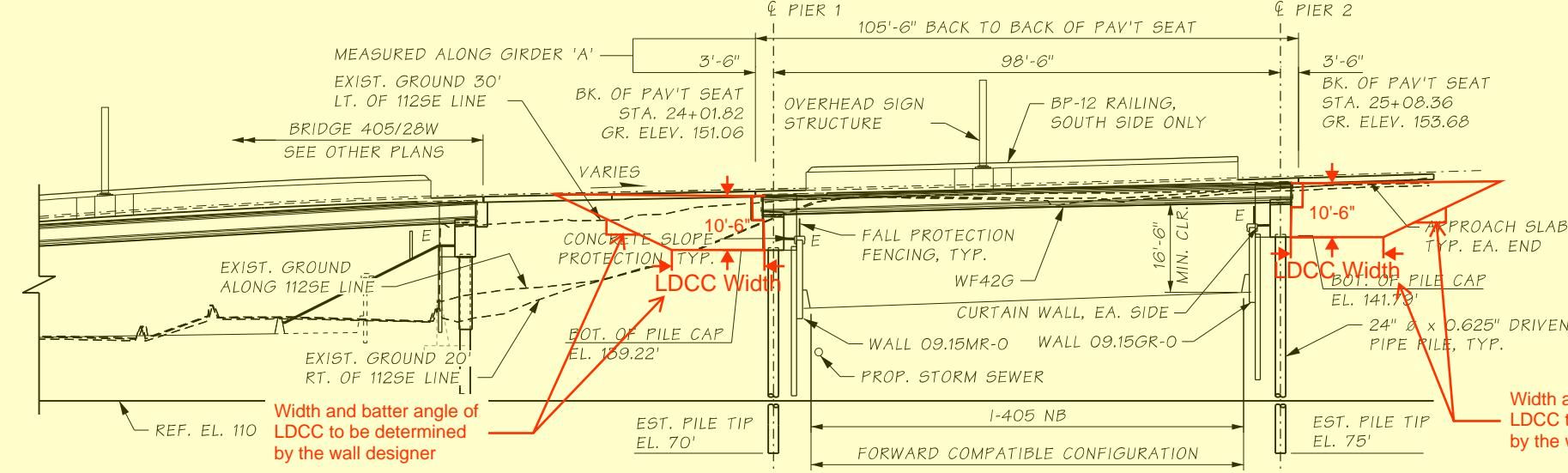
WF42G P.C. GIRDERS  
"A" DIMENSIONS = VARIES  
BRIDGE DECK PROTECTION SYSTEM = TYPE 1 ~ EPOXY COATED REINFORCING  
CAST-IN-PLACE CONCRETE STRENGTH SHALL BE 4000 PSI

PT. OF MIN. VERT. CLR. 28E  
112SE STA. 25+08.04 (29.87' RT.)  
405NB STA. 7786+66.06 (48.00' RT.)



.AN

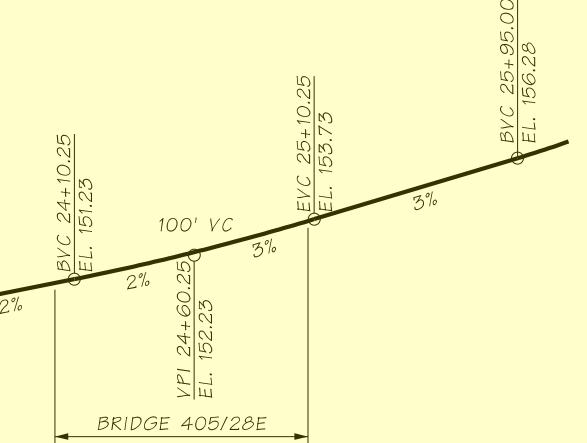
ALL SPANS AND BK. TO BK. PAV'T SEAT ARE MEASURED ALONG GIRDER 'A'.  
ALL PIER BEARINGS ARE N27°15'08"E



## ELEVATION

GRADE ELEVATIONS ARE FINISHED GRADES AT TOP OF BRIDGE DECK ON 112SE LINE AND ARE EQUAL TO PROFILE GRADE.  
SEE RETAINING WALL PLANS AND WSDOT STD PLAN A-50.10 FOR EMBANKMENT DETAILS AT BRIDGE END.

— Width and batter angle of LDCC to be determined by the wall designer



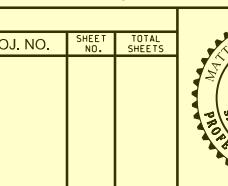
## 112SE LINE PROFILE

P.C. GIRDERS (WF42G)

FILE NO. \_\_\_\_\_ SHEET. D

DATUM  
NAVD 1988

c:\users\xnbr\documents\projectwise\workingdir\wsdot\dms13259\XL5467_01_DE_BD		
Design Mgr:	TOM NETTLETON	RELEASE FOR CONSTRUCTION RECORD
Designed By:	M. BAUGHMAN	
Checked By:	M. DASTFAN	
Detailed By:	K. BUNGER	
Current Revision By:		
Date:	2/2/2021	
Time:	12:11:10 PM	DESCRIPTION



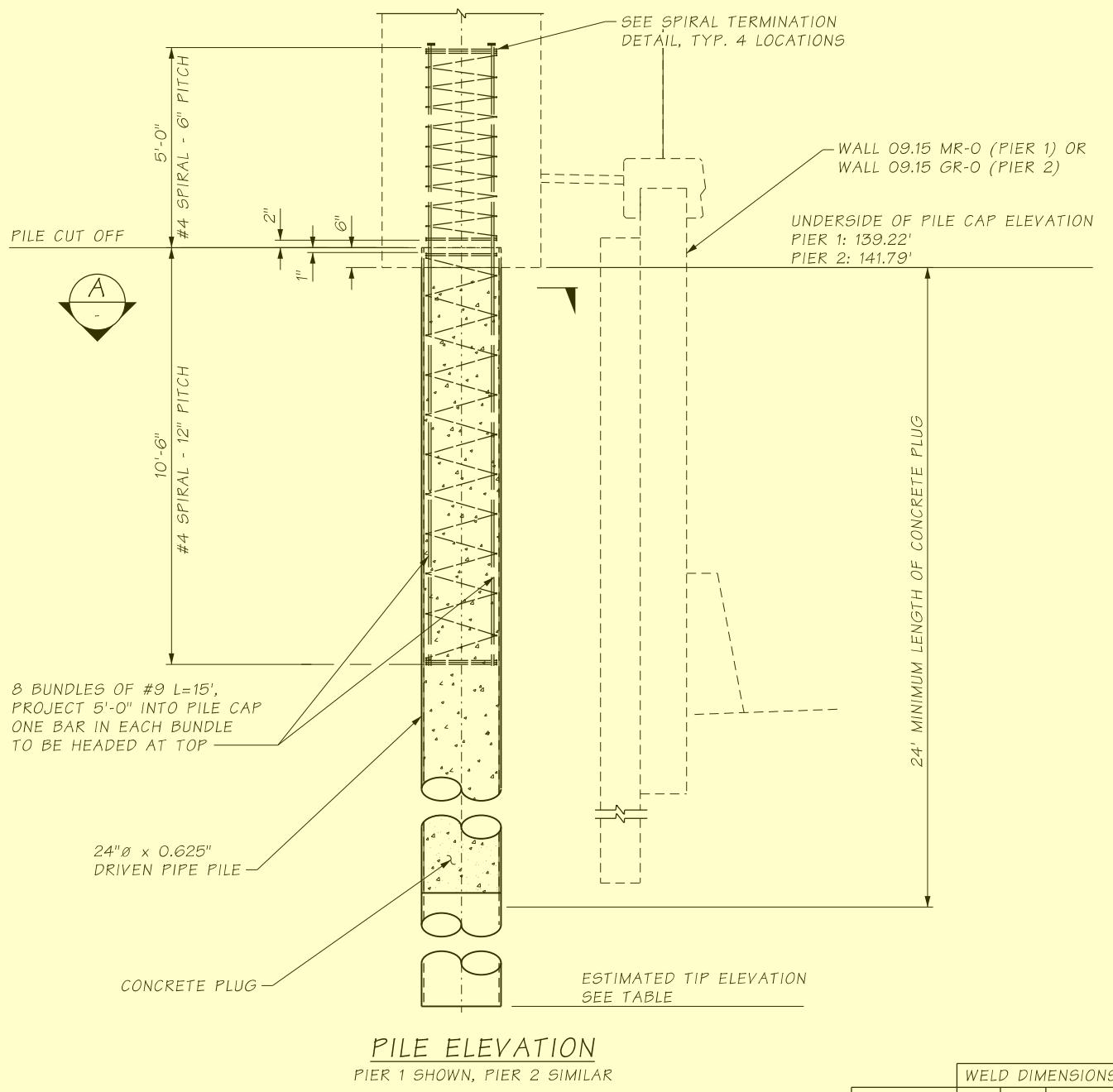
 Washington State  
Department of Transportation

**I-405; RENTON TO BELLEVUE WIDENING**

13TH AVENUE SE OVER NB | 40

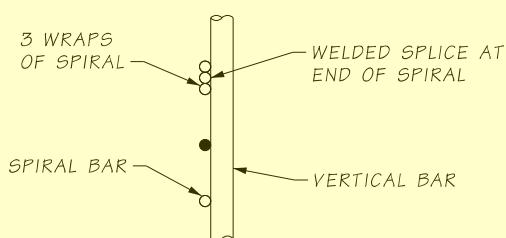
## BRIDGE LAYOUT

PLAN REF. NO.  
**BG28E-0**  
SHEET  
OF  
SHEETS



PILE ELEVATION  
PIER 1 SHOWN, PIER 2 SIMILAR

BAR SIZE	WELD DIMENSIONS (IN.)		
	S	E	L (LENGTH)
SPIRAL #4	1/16	1/16	6



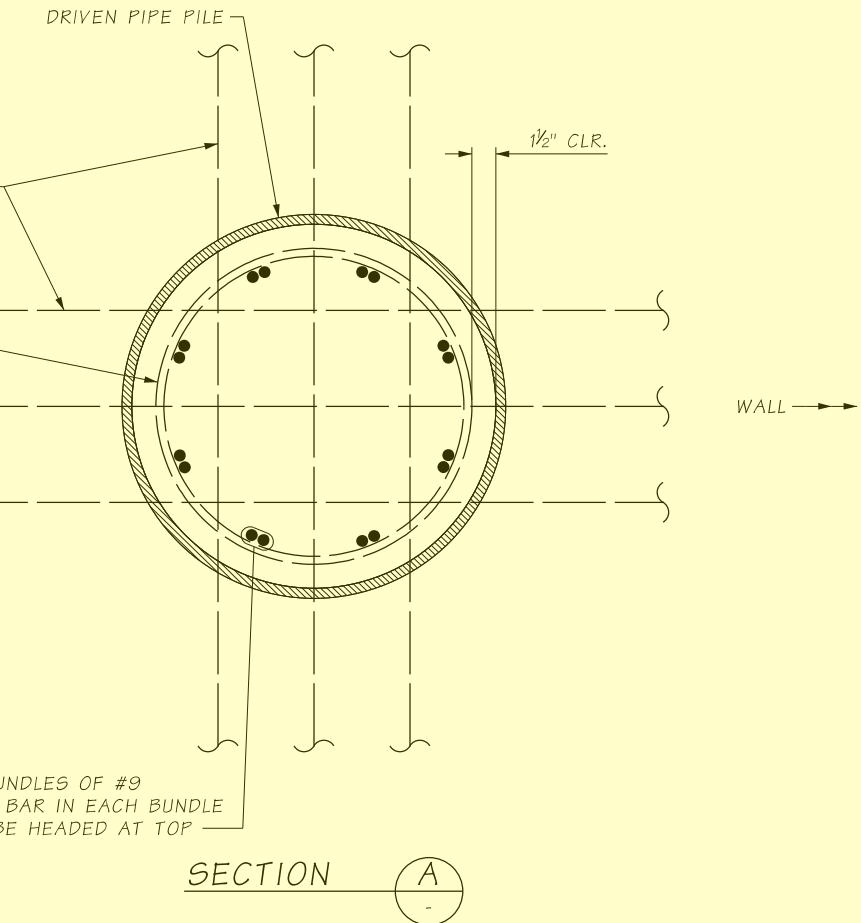
SPIRAL TERMINATION DETAIL  
REQUIRED AT ALL LOCATIONS WHERE SPIRAL TERMINATES.

WELDING SHALL MEET THE REQUIREMENTS OF STD. SPEC. 6-02.3(24)E.  
FOR WELD DIMENSIONS, SEE TABLE. NO WELDING OF SPIRALS IS  
PERMITTED AFTER THE COLUMN CAGE IS ASSEMBLED. SPIRAL SHALL  
BE FIELD OR SHOP WELDED INDEPENDENTLY AND THEN ASSEMBLED  
AROUND THE COLUMN LONGITUDINAL STEEL AFTER WELDING.

#### WELDED SPIRAL SPLICING DETAIL

WELDING SHALL MEET THE REQUIREMENTS OF STD. SPEC. 6-02.3(24)E.  
FOR WELD DIMENSIONS, SEE TABLE. NO WELDING OF SPIRALS IS  
PERMITTED AFTER THE COLUMN CAGE IS ASSEMBLED. SPIRAL SHALL  
BE FIELD OR SHOP WELDED INDEPENDENTLY AND THEN ASSEMBLED  
AROUND THE COLUMN LONGITUDINAL STEEL AFTER WELDING.

SEE SPIRAL TERMINATION  
DETAIL, TYP. 4 LOCATIONS  
WALL 09.15 MR-O (PIER 1) OR  
WALL 09.15 GR-O (PIER 2)  
UNDERSIDE OF PILE CAP ELEVATION  
PIER 1: 139.22'  
PIER 2: 141.79'



SECTION A-A

PIER	NUMBER OF PILES	PILE DIAMETER (D) IN.	STEEL THICKNESS (T) IN.	ESTIMATED TIP ELEV.	MIN. PILE TIP ELEV.	FACTORDED DEMAND (KIPS)	MIN. BEARING CAPACITY (KIPS)	UNFACTORDED DEAD LOAD (KIPS)	FACTORDED DOWNDRAG FORCE (KIPS)
1	6	24	5/8	70	95	520	800	255	520
2	7	24	5/8	75	100	485	750	255	0

1. STEEL PIPE PILES SHALL COMPLY WITH ASTM A709, GRADE 50 (FY=50 KSI)
2. ALL PILES ARE ONLY UNDER COMPRESSION.
3. "FACTORDED DEMAND" IS COMPRESSIVE DEMAND FROM STRENGTH 1 LOAD COMBINATION AT TOP OF PILE AND DOES NOT INCLUDE DOWNDRAG.
4. "MIN. BEARING CAPACITY" IS THE MINIMUM REQUIRED ULTIMATE CAPACITY ACHIEVED AT THE END OF PILE DRIVING. IT IS CALCULATED BY DIVIDING "FACTORDED DEMAND" BY RESISTANCE FACTOR. RESISTANCE FACTOR OF 0.65 HAS BEEN USED FOR CALCULATION OF ULTIMATE PILE CAPACITY AND "ESTIMATED TIP ELEV.", ACCORDING TO "GEOTECHNICAL ENGINEERING REPORT: BRIDGE 28", DATED 22 DEC. 2020.
5. THE USE OF THE 0.65 COMPRESSION RESISTANCE FACTOR REQUIRES DEVELOPMENT OF DRIVING CRITERIA USING DYNAMIC TESTING AT THE BEGINNING OF THE PRODUCTION PILE DRIVING, QUALITY CONTROL BY DYNAMIC TESTING ON AT LEAST TWO PILES. GEOTECHNICAL ENGINEER TO DEFINE THE RE-STRIKE CRITERIA, IF NEEDED.
6. IF PILES REACH REFUSAL WITH PILE TIP HIGHER THAN THE SPECIFIED "MIN. PILE TIP ELEVATION", BRIDGE ENGINEER SHALL BE INFORMED TO ASSESS WHETHER PILES ARE ACCEPTABLE.
7. DOWNDRAG FORCES ON PILES HAVE NOT BEEN CONSIDERED FOR DETERMINING PILE LENGTHS. FACTORED DOWNDRAG FORCE IN COMBINATION WITH FACTORED DEAD LOAD HAS BEEN CONSIDERED FOR STRUCTURAL DESIGN OF PILES.
8. CORROSION RATE OF 0.001 INCH-PER-YEAR HAS BEEN CONSIDERED FOR THE EXTERIOR FACE OF PILES ONLY.
9. STEEL PILE FABRICATION AND MATERIAL TESTING SHALL CONFORM TO SECTION 6-05.3(5).OPT1.GB6 OF THE GENERAL SPECIAL PROVISIONS IN APPENDIX B3 OF THE CONFORMED RFP.
10. STEEL PILE SPLICES SHALL CONFORM TO SECTION 6-05.3(6).OPT1.GB6 OF THE GENERAL SPECIAL PROVISIONS IN APPENDIX B3 OF THE CONFORMED RFP.

**FLATIRON**

**LANE** 

**wood.**

In Association with

## **Appendix A Calculation Package**

# Appendix A

## Section 0-1a - Site class v1.0 AASHTO\_BR28\_2020.09.09

### Calculation of Average Blow Count

#### Method B: method

Reference: AASHTO LRFD Manual, Table C3.10.3.1-1

Project Name

Project Engineer

Boring R2B-68vw		Boring W-148		Boring H-2-64PP		Boring R2B-69		Boring H-1-64PP		Boring R2B-71vw		Boring R2B-70vw		Boring W-147																	
i, Layer or di, Layer Sample Number	N, Layer Blow Count in s in Feet Thicknesses Blows	i, Layer or di, Layer Sample Number	N, Layer Blow Count in s in Feet Thicknesses Blows	i, Layer or di, Layer Sample Number	N, Layer Blow Count in s in Feet Thicknesses Blows	i, Layer or di, Layer Sample Number	N, Layer Blow Count in s in Feet Thicknesses Blows	i, Layer or di, Layer Sample Number	N, Layer Blow Count in s in Feet Thicknesses Blows	i, Layer or di, Layer Sample Number	N, Layer Blow Count in s in Feet Thicknesses Blows	i, Layer or di, Layer Sample Number	N, Layer Blow Count in s in Feet Thicknesses Blows	i, Layer or di, Layer Sample Number	N, Layer Blow Count in s in Feet Thicknesses Blows																
1	0.5	10	0.05	94	0.026596	1	2.5	21	0.285714	1	0.5	14	0.0357143	1	4	20	0.25														
2	3.5	13	0.269231			2	2.5	4	0.027174	2	6	20	0.2	2	6	20	0.3														
3	3	9	0.333333			3	2.5	100	0.025	3	5	21	0.238095	3	5	18	0.277778														
4	2	9	0.222222			4	2.5	100	0.025	4	4	20	0.2	4	5	19	0.2631579														
5	4	11	0.363636			5	2.5	100	0.025	5	6	19	0.315789	5	5	20	0.25														
6	6	14	0.428571			6	2.5	100	0.025	6	5	21	0.238095	6	5	16	0.3125														
7	5	14	0.357143			7	8	65	0.123077	7	10	26	0.384615	7	5	11	0.4545455														
8	5	14	0.357143			8	2	73	0.027397	8	5	31	0.16129	8	4	25	0.16														
9	5	16	0.3125			9	5	48	0.104167	9	5	28	0.178571	9	6	19	0.3157895														
10	5	15	0.333333			10	5	32	0.15625	10	5	65	0.076923	10	5	17	0.2941176														
11	5	18	0.277778			11	8	32	0.25	11	5	20	0.25	11	5	43	0.1162791														
12	5	16	0.3125			12	2	30	0.066667	12	5	29	0.172414	12	5	36	0.138889														
13	5	17	0.294118			13	5	38	0.222222	13	5	28	0.178571	13	5	18	0.277778														
14	5	19	0.263158			14	2	35	0.057143	14	5	50	0.121551	14	5	13	0.3846154														
15	5	18	0.277778			15	8	32	0.25	15	5	41	0.121551	15	5	20	0.25														
16	5	17	0.294118			16	9	29	0.310345	16	5	58	0.086207	16	5	15	0.3333333														
17	5	20	0.25			17	3	38	0.078947	17	5	73	0.084943	17	5	19	0.2631579														
18	5	21	0.238095			18	5	25	0.2	18	5	76	0.065789	18	5	18	0.277778														
19	5	26	0.192308			19	5	29	0.172414	19	5	63	0.079365	19	5	20	0.25														
20	5	32	0.15625			20	7	0.1	20	#DIV/0!	20	5	19	0.2631579	20	#DIV/0!	20	#DIV/0!													
21	5	50	0.1			21	#DIV/0!	21	#DIV/0!	21	#DIV/0!	21	5	23	0.2173913	21	#DIV/0!	21	#DIV/0!												
22	6	57	0.105263			22	#DIV/0!	22	#DIV/0!	22	#DIV/0!	22	7	27	0.2592593	22	#DIV/0!	22	#DIV/0!												
23	#DIV/0!	23	#DIV/0!			23	#DIV/0!	23	#DIV/0!	23	#DIV/0!	23	5	20	0.25	23	#DIV/0!	23	#DIV/0!												
24	#DIV/0!	24	#DIV/0!			24	#DIV/0!	24	#DIV/0!	24	#DIV/0!	24	5	18	0.277778	24	#DIV/0!	24	#DIV/0!												
25	#DIV/0!	25	#DIV/0!			25	#DIV/0!	25	#DIV/0!	25	#DIV/0!	25	5	18	0.277778	25	#DIV/0!	25	#DIV/0!												
Totals	100	5.788478		Totals	100	2.524779		Totals	100	3.290774		Totals	100	6.6737039		Totals	100	3.5203733		Totals	100	4.751131		Totals	100	6.993288		Totals	100	4.649749	
Average N =	17	blows/foot		Average N =	40	blows/foot		Average N =	30	blows/foot		Average N =	15	blows/foot		Average N =	28	blows/foot		Average N =	21	blows/foot		Average N =	14	blows/foot		Average N =	22	blows/foot	
Site Class D	Site Class D	Site Class D	Site Class E	Site Class D	Site Class D	Site Class D	Site Class D	Site Class D	Site Class D	Site Class D	Site Class D	Site Class D	Site Class D	Site Class D	Site Class D																
Boring R2B-72	Boring HC-CPT3	Boring W-119	Boring R2B-67	Boring R2B-120	Boring GEO-1	Boring GEO-2	Boring W-65									100															
i, Layer or di, Layer Sample Number	N, Layer Blow Count in s in Feet Thicknesses Blows	i, Layer or di, Layer Sample Number	N, Layer Blow Count in s in Feet Thicknesses Blows	i, Layer or di, Layer Sample Number	N, Layer Blow Count in s in Feet Thicknesses Blows	i, Layer or di, Layer Sample Number	N, Layer Blow Count in s in Feet Thicknesses Blows	i, Layer or di, Layer Sample Number	N, Layer Blow Count in s in Feet Thicknesses Blows	i, Layer or di, Layer Sample Number	N, Layer Blow Count in s in Feet Thicknesses Blows	i, Layer or di, Layer Sample Number	N, Layer Blow Count in s in Feet Thicknesses Blows	i, Layer or di, Layer Sample Number	N, Layer Blow Count in s in Feet Thicknesses Blows	i, Layer or di, Layer Sample Number	N, Layer Blow Count in s in Feet Thicknesses Blows	i, Layer or di, Layer Sample Number	N, Layer Blow Count in s in Feet Thicknesses Blows	i, Layer or di, Layer Sample Number	N, Layer Blow Count in s in Feet Thicknesses Blows										
1	4	30	0.133333			1	6.89	592.95	0.01162	1	2.50	70	0.035714	1	2.50	30	0.1315789	1	2.50	30	0.064103	1	2.00	12	0.166667						
2	3	25	0.12			2	6.40	759.9	0.084822	2	2.50	78	0.032051	2	2.50	33	0.0757576	2	2.50	33	0.0792593	2	3.00	15	0.2						
3	2	17	0.117647			3	6.56	819.6	0.080803	3	2.50	86	0.029051	3	3.00	38	0.0789474	3	2.50	20	0.125	3	2.50	33	0.0781215						
4	3	16	0.1875			4	6.40	908.28	0.0207046	4	2.50	81	0.030964	4	2.00	54	0.037037	4	2.50	14	0.1785714	4	2.50	18	0.138889						
5	2	17	0.117647			5	6.56	903.98	0.07257	5	5.00	100	0.05	5	3.00	100	0.03	5	5.00	43	0.1162791	5	2.50	25	0.125						
6	5	29	0.172414			6	6.56	891.63	0.068689	6	5.00	100	0.05	6	6.00	200	0.02	6	5.00	17	0.2941176	6	2.50	24	0.119363						
7	5	36	0.133333			7	6.40	1075.25	0.050435	7	5.00	100	0.05	7	5.00	66	0.0793244	7	5.00	14	0.1785714	7	5.00	15	0.169937						
8	5	72	0.069444			8	5	100	0.05	8	5	76	0.0657905	8	5	5	9	0.5588235	8	2.5	35	0.0711459	8	2.5	15	0.119048					
9	5	76	0.068789			9	5	100	0.05	9	5	85	0.0588235	9	5	4	24	0.2083333	9	5	24	0.2424342	9	5	80	0.23					
10	5	25	0.2			10	5	72	0.069444	10	5	80	0.0625	10	5	48	0.1041667	10	60	48	1.25	10	#DIV/0!	11	#DIV/0!						
11	5	24	0.208333			11	60	72	0.083333	11	60	100	0.05	11	60	100	0.05	11	60	12	#DIV/0!	11	#DIV/0!	12	#DIV/0!						
12	5	36	0.138889			12	#DIV/0!	12	#DIV/0!	12	#DIV/0!	12	#DIV/0!	13	#DIV/0!	13	#DIV/0!	13	#DIV/0!	13	#DIV/0!	14	#DIV/0!	14	#DIV/0!	14	#DIV/0!				
13	5	32	0.15625			13	#DIV/0!	13	#DIV/0!	13	#DIV/0!	13	#DIV/0!	14	#DIV/0!	14	#DIV/0!	14	#DIV/0!	14	#DIV/0!	15	#DIV/0!	15	#DIV/0!	15	#DIV/0!				
14	5	28	0.178571			14	#DIV/0!	14	#DIV/0!	14	#DIV/0!	14	#DIV/0!	15	#DIV/0!	15	#DIV/0!	15	#DIV/0!	15	#DIV/0!	16	#DIV/0!	16	#DIV/0!	16	#DIV/0!				
15	5	27	0.185185			15	#DIV/0!	15	#DIV/0!	15	#DIV/0!	15	#DIV/0!	16	#DIV/0!	16	#DIV/0!	16	#DIV/0!	16	#DIV/0!	17	#DIV/0!	17	#DIV/0!	17	#DIV/0!				
16	5	30	0.166667			16	#DIV/0!	16	#DIV/0!	16	#DIV/0!	16	#DIV/0!	17	#DIV/0!	17	#DIV/0!	17	#DIV/0!	17	#DIV/0!	18	#DIV/0!	18	#DIV/0!	18	#DIV/0!				
17	5	33	0.151515			17	#DIV/0!	17	#DIV/0!	17	#DIV/0!	17	#DIV/0!	18	#DIV/0!	18	#DIV/0!	18	#DIV/0!	18	#DIV/0!	19	#DIV/0!	19	#DIV/0!	19	#DIV/0!				
18	5	34	0.147059			18	#DIV/0!	18	#DIV/0!	18	#DIV/0!	18	#DIV/0!	19	#DIV/0!	19	#DIV/0!	19	#DIV/0!	19	#DIV/0!	20	#DIV/0!	20	#DIV/0!	20	#DIV/0!				
19	5	26	0.192308			19	#DIV/0!	19	#DIV/0!	19	#DIV/0!	19	#DIV/0!	20	#DIV/0!	20	#DIV/0!	20	#DIV/0!	20	#DIV/0!	21	#DIV/0!	21	#DIV/0!	21	#DIV/0!				
20	5	21	0.238095			20	#DIV/0!	20	#DIV/0!	20	#DIV/0!	20	#DIV/0!	21	#DIV/0!	21	#DIV/0!	21	#DIV/0!	21	#DIV/0!	22	#DIV/0!	22	#DIV/0!	22	#DIV/0!				
21	5	26	0.192308			21	#DIV/0!	21	#DIV/0!	21	#DIV/0!	21	#DIV/0!	22	#DIV/0!	22	#DIV/0!	22	#DIV/0!	22	#DIV/0!	23	#DIV/0!	23	#DIV/0!	23	#DIV/0!				
22	6	34	0.176471			22	#DIV/0!</																								

# Appendix A

## Section 0-1b - Site class v1.0 AASHTO\_BR28\_2020.09.09

### Calculation of Average Blow Count

#### Method B: method

Reference: AASHTO LRFD Manual, Table C3.10.3.1-1

Project Name  
Project Engineer

Boring W-66		Boring R2B-73		Boring NRAR-1-05		Boring NRAR-2-05		Boring W-67		Boring W-68		Boring		Boring																			
i, Layer or Sample Number	N, Layer Blow Count in Blows per Foot																																
1	2.5	14	0.178571	1	4	8	0.5	1	3.5	5	0.7	1	2.5	100	0.025																		
2	2.5	7	0.357143	2	3	6	0.5	2	2	3	0.666667	2	2	3	16	0.1875																	
3	5	3	1.666667	3	2	6	0.333333	3	3	5	0.6	3	3	5	10	0.25																	
4	5	2	2.5	4	3	12	0.25	4	2	23	0.086957	4	2.5	8	0.3125																		
5	5	16	0.3125	5	3	10	0.3	5	3	23	0.130435	5	5	15	0.333333																		
6	5	59	0.084746	6	4	38	0.105263	6	5	14	0.37143	6	5	13	0.3846154																		
7	5	66	0.075758	7	5	54	0.092593	7	5	11	0.454545	7	5	16	0.3125																		
8	5	70	0.071429	8	5	37	0.135135	8	76.5	11	6.954545	8	76.5	16	4.78125																		
9	5	78	0.064103	9	71	37	1.918919	9	#DIV/0!	9	#DIV/0!	9	#DIV/0!	9	#DIV/0!																		
10	5	66	0.075758	10	#DIV/0!																												
11	5	67	0.074627	11	#DIV/0!																												
12	5	93	0.053763	12	#DIV/0!																												
13	45	93	0.483871	13	#DIV/0!																												
14	#DIV/0!																																
15	#DIV/0!																																
16	#DIV/0!																																
17	#DIV/0!																																
18	#DIV/0!																																
19	#DIV/0!																																
20	#DIV/0!																																
21	#DIV/0!																																
22	#DIV/0!																																
23	#DIV/0!																																
24	#DIV/0!																																
25	#DIV/0!																																
Totals	100	5.998934		Totals	100	4.135243		Totals	100	9.950292		Totals	100	7.203889		Totals	100	8.0315171		Totals	100	6.617775		Totals	100	0	#DIV/0!		Totals	100	0	#DIV/0!	
Average N =	17	blows/foot		Average N =	24	blows/foot		Average N =	10	blows/foot		Average N =	14	blows/foot		Average N =	12	blows/foot		Average N =	15	blows/foot		Average N =	#DIV/0!	blows/foot		Average N =	#DIV/0!	blows/foot			

Site Class D

Site Class D

Site Class E

Site Class E

Site Class E

Site Class D

Boring																							
i, Layer or Sample Number	N, Layer Blow Count in Blows per Foot																						
1	#DIV/0!	1	#DIV/0!	2	#DIV/0!	2	#DIV/0!	3	#DIV/0!	3	#DIV/0!	4	#DIV/0!	4	#DIV/0!								
2	#DIV/0!	2	#DIV/0!	3	#DIV/0!	3	#DIV/0!	4	#DIV/0!	4	#DIV/0!	5	#DIV/0!	5	#DIV/0!								
3	#DIV/0!	3	#DIV/0!	4	#DIV/0!	4	#DIV/0!	5	#DIV/0!	5	#DIV/0!	6	#DIV/0!	6	#DIV/0!								
4	#DIV/0!	4	#DIV/0!	5	#DIV/0!	5	#DIV/0!	6	#DIV/0!	6	#DIV/0!	7	#DIV/0!	7	#DIV/0!								
5	#DIV/0!	5	#DIV/0!	6	#DIV/0!	6	#DIV/0!	7	#DIV/0!	7	#DIV/0!	8	#DIV/0!	8	#DIV/0!								
6	#DIV/0!	6	#DIV/0!	7	#DIV/0!	7	#DIV/0!	8	#DIV/0!	8	#DIV/0!	9	#DIV/0!	9	#DIV/0!								
7	#DIV/0!	7	#DIV/0!	8	#DIV/0!	8	#DIV/0!	9	#DIV/0!	9	#DIV/0!	10	#DIV/0!	10	#DIV/0!								
8	#DIV/0!	8	#DIV/0!	9	#DIV/0!	9	#DIV/0!	10	#DIV/0!	10	#DIV/0!	11	#DIV/0!	11	#DIV/0!								
9	#DIV/0!	9	#DIV/0!	10	#DIV/0!	10	#DIV/0!	11	#DIV/0!	11	#DIV/0!	12	#DIV/0!	12	#DIV/0!								
10	#DIV/0!	10	#DIV/0!	11	#DIV/0!	11	#DIV/0!	12	#DIV/0!	12	#DIV/0!	13	#DIV/0!	13	#DIV/0!								
11	#DIV/0!	11	#DIV/0!	12	#DIV/0!	12	#DIV/0!	13	#DIV/0!	13	#DIV/0!	14	#DIV/0!	14	#DIV/0!								
12	#DIV/0!	12	#DIV/0!	13	#DIV/0!	13	#DIV/0!	14	#DIV/0!	14	#DIV/0!	15	#DIV/0!	15	#DIV/0!								
13	#DIV/0!	13	#DIV/0!	14	#DIV/0!	14	#DIV/0!	15	#DIV/0!	15	#DIV/0!	16	#DIV/0!	16	#DIV/0!								
14	#DIV/0!	14	#DIV/0!	15	#DIV/0!	15	#DIV/0!	16	#DIV/0!	16	#DIV/0!	17	#DIV/0!	17	#DIV/0!								
15	#DIV/0!	15	#DIV/0!	16	#DIV/0!	16	#DIV/0!	17	#DIV/0!	17	#DIV/0!	18	#DIV/0!	18	#DIV/0!								
16	#DIV/0!	16	#DIV/0!	17	#DIV/0!	17	#DIV/0!	18	#DIV/0!	18	#DIV/0!	19	#DIV/0!	19	#DIV/0!								
17	#DIV/0!	17	#DIV/0!	18	#DIV/0!	18	#DIV/0!	19	#DIV/0!	19	#DIV/0!	20	#DIV/0!	20	#DIV/0!								
18	#DIV/0!	18	#DIV/0!	19	#DIV/0!	19	#DIV/0!	20	#DIV/0!	20	#DIV/0!	21	#DIV/0!	21	#DIV/0!								
19	#DIV/0!	19	#DIV/0!	20	#DIV/0!	20	#DIV/0!	21	#DIV/0!	21	#DIV/0!	22	#DIV/0!	22	#DIV/0!								
20	#DIV/0!	20	#DIV/0!	21	#DIV/0!	21	#DIV/0!	22	#DIV/0!	22	#DIV/0!	23	#DIV/0!	23	#DIV/0!								
21	#DIV/0!	21	#DIV/0!	22	#DIV/0!	22	#DIV/0!	23	#DIV/0!	23	#DIV/0!	24	#DIV/0!	24	#DIV/0!								
22	#DIV/0!	22	#DIV/0!	23	#DIV/0!	23	#DIV/0!	24	#DIV/0!	24	#DIV/0!	25	#DIV/0!	25	#DIV/0!								
23	#DIV/0!	23	#DIV/0!	24	#DIV/0!	24	#DIV/0!	25	#DIV/0!	25	#DIV/0!	Totals	0	#DIV/0!									
Average N =	#DIV/0!	blows/foot		Average N =	#DIV/0!	blows/foot		Average N =	#DIV/0!	blows/foot		Average N =	#DIV/0!	blows/foot		Average N =	#DIV/0!	blows/foot		Average N =	#DIV/0!	blows/foot	
Totals	0	#DIV/0!		Totals	0	#DIV/0!		Totals	0	#DIV/0!		Totals	0	#DIV/0!		Totals	0	#DIV/0!		Totals	0	#DIV/0!	

SECTION 3: LOADS AND LOAD FACTORS	
Table 3.10.3.1-1—Site Class Definitions	
Soil Type and Profile	
A Hard rock with measured shear wave velocity, $V_s > 5,000 \text{ ft/s}$	
B Rock with $2,500 \text{ ft/sec} < V_s < 5,000 \text{ ft/s}$	
C Very dense soil and soil rock with $1,200 \text{ ft/sec} < V_s < 2,500 \text{ ft/s}$ , or either $N > 50$ blow/ft, or $\pi_s > 2.0 \text{ ksf}$	
D Stiff soil with $600 \text{ ft/sec} < V_s < 15$ blow/ft, or with either $N < 15$ blow/ft, or $\pi_s < 1.0 \text{ ksf}$ , or $1.0 < \pi_s < 2.0 \text{ ksf}$	
E Soil profile with $V_s < 600 \text{ ft/sec}$ or with either $N < 15$ blow/ft, or $\pi_s < 1.0 \text{ ksf}$ , or any profile with more than 10 ft of soft clay defined as soil with $P_f > 20$ , $w > 40$ percent and $\pi_s < 0.5 \text{ ksf}$	
F Soils requiring site-specific evaluations, such as:	
• Peats or highly organic clays ( $H > 10 \text{ ft}$ of peat or highly organic clay where $H =$ thickness of soil)	
• Very high plasticity clays ( $H > 25 \text{ ft}$ with $P_f > 75$ )	
• Very thick soft-medium stiff clays ( $H > 120 \text{ ft}$ )	
Exceptions: Where the soil properties are not known in sufficient detail to determine the site class, a site investigation shall be undertaken sufficient to determine the site class. Site classes E or F should not be assumed unless the authority having jurisdiction determines that site classes E or F could be present at the site or in the event that site classes E or F are established by geotechnical data.	
where:	
$\bar{V}_s$ = average shear wave velocity for the upper 100 ft of the soil profile	
$\bar{N}$ = average Standard Penetration Test (SPT) blow count (blows/ft) (ASTM D1886) for the upper 100 ft of the soil profile	
$\bar{\pi}_s$ = average undrained shear strength in ksf (ASTM D2166 or ASTM D2850) for the upper 100 ft of the soil profile	
$P_f$ = plasticity index (ASTM D4318)	
$w$ = moisture content (ASTM D2216)	

# Unified Hazard Tool

 Please do not use this tool to obtain ground motion parameter values for the design code reference documents covered by the [U.S. Seismic Design Maps web tools](#) (e.g., the International Building Code and the ASCE 7 or 41 Standard). The values returned by the two applications are not identical.

## ^ Input

### Edition

Dynamic: Conterminous U.S. 2014 (u...)

### Spectral Period

Peak Ground Acceleration

### Latitude

Decimal degrees

47.5567

### Time Horizon

Return period in years

210

### Longitude

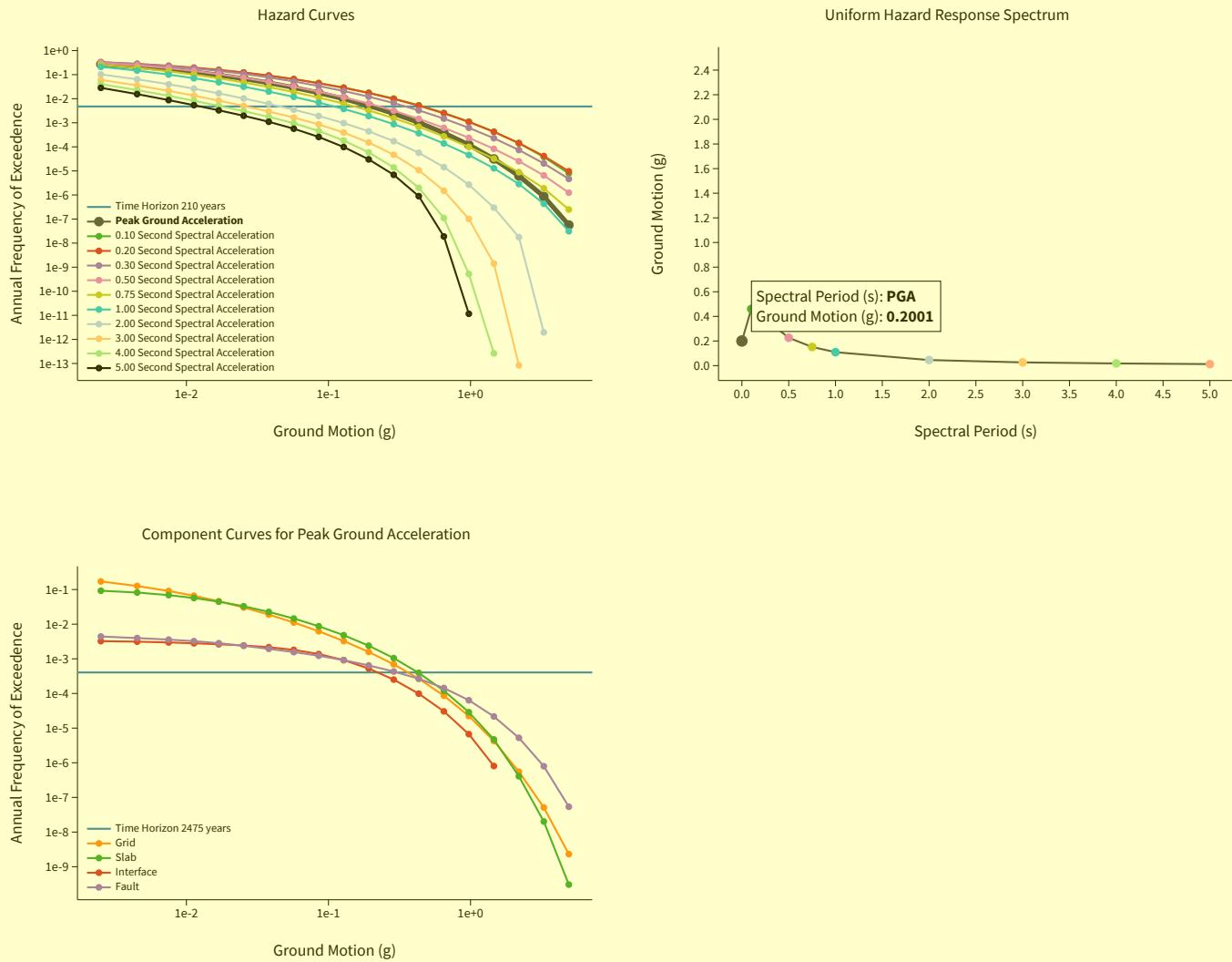
Decimal degrees, negative values for western longitudes

-122.19

### Site Class

760 m/s (B/C boundary)

## ^ Hazard Curve



[View Raw Data](#)

**Table 6-4** Values of Site Coefficient,  $F_{pga}$ , for Peak Ground Acceleration

Site Class	Mapped Peak Ground Acceleration Coefficient (PGA)					
	PGA ≤ 0.10	PGA = 0.2	PGA = 0.3	PGA = 0.4	PGA = 0.5	PGA ≥ 0.6
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.9	0.9	0.9	0.9	0.9	0.9
C	1.3	1.2	1.2	1.2	1.2	1.2
D	1.6	1.4	1.3	1.2	1.1	1.1
E	2.4	1.9	1.6	1.4	1.2	1.1
F	*	*	*	*	*	*

\* Site-specific response geotechnical investigation and dynamic site response analysis should be considered.

Note: Use straight line interpolation for intermediate values of PGA.

$$\text{As} = \text{pga} * F_{pga} = 0.2 * 1.4 = 0.28$$

$$0.5 * \text{As} = 0.14$$

# Unified Hazard Tool



Please do not use this tool to obtain ground motion parameter values for the design code reference documents covered by the [U.S. Seismic Design Maps web tools](#) (e.g., the International Building Code and the ASCE 7 or 41 Standard). The values returned by the two applications are not identical.

## Input

### Edition

Dynamic: Conterminous U.S. 2014 (update) (v4.2.0)

### Spectral Period

0.20 Second Spectral Acceleration

### Latitude

Decimal degrees

47.5567

### Time Horizon

Return period in years

210

### Longitude

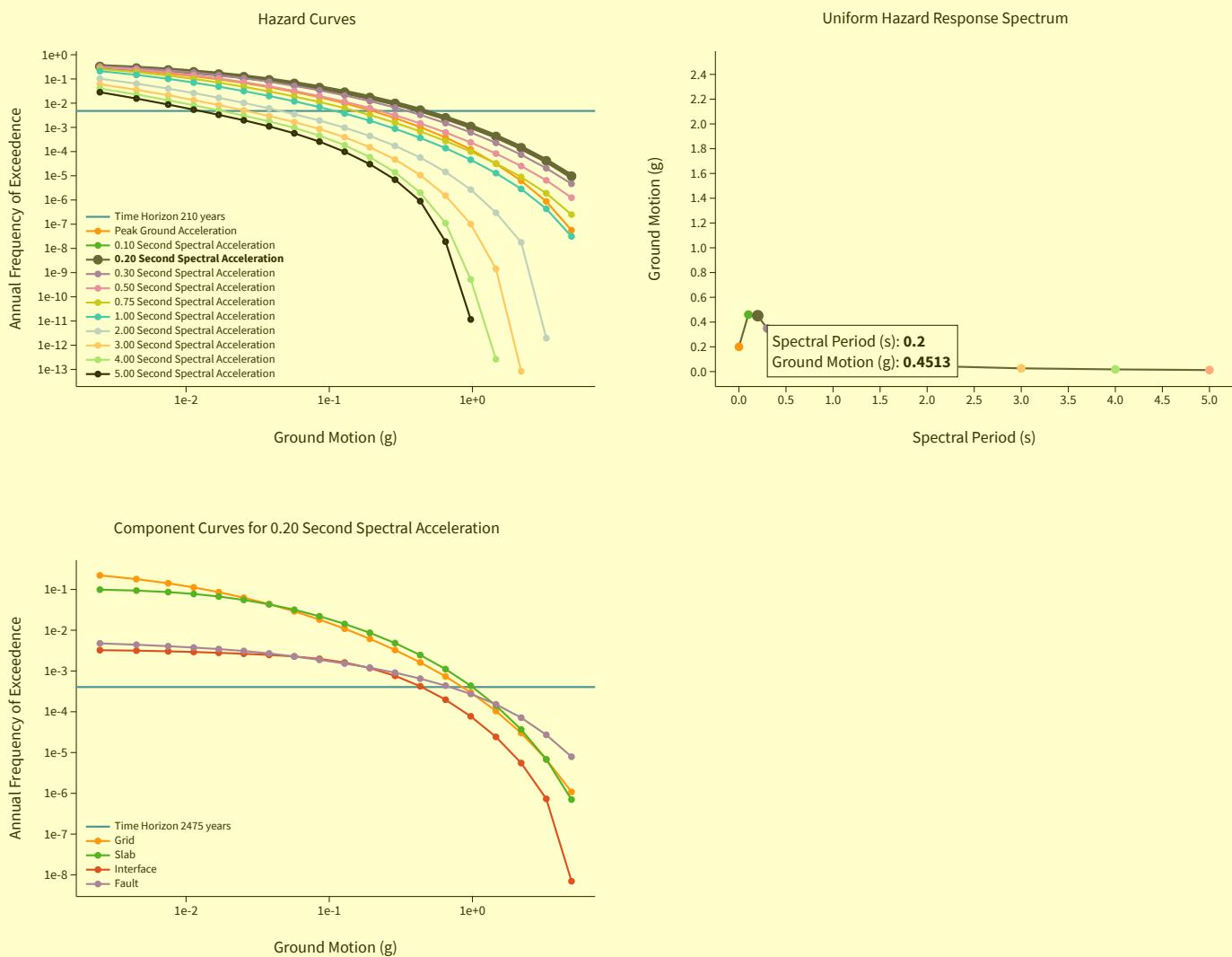
Decimal degrees, negative values for western longitudes

-122.19

### Site Class

760 m/s (B/C boundary)

^ Hazard Curve



[View Raw Data](#)

**Table 6-5** Values of Site Coefficient,  $F_a$ , for 0.2-sec Period Spectral Acceleration

Site Class	Mapped Spectral Acceleration Coefficient at Period 0.2 sec (Ss)					
	Ss ≤ 0.25	Ss = 0.50	Ss = 0.75	Ss = 1.00	Ss = 1.25	Ss ≥ 1.50
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.9	0.9	0.9	0.9	0.9	0.9
C	1.3	1.3	1.2	1.2	1.2	1.2
D	1.6	1.4	1.2	1.1	1.0	1.0
E	2.4	1.7	1.3	1.0	0.9	0.9
F	*	*	*	*	*	*

\* Site-specific response geotechnical investigation and dynamic site response analysis should be considered.

Note: Use straight line interpolation for intermediate values of  $S_s$ .

$$Ss = 0.4513 \text{ g}$$

$$Fa = 1.439$$

# Unified Hazard Tool



Please do not use this tool to obtain ground motion parameter values for the design code reference documents covered by the [U.S. Seismic Design Maps web tools](#) (e.g., the International Building Code and the ASCE 7 or 41 Standard). The values returned by the two applications are not identical.

## Input

### Edition

Dynamic: Conterminous U.S. 2014 (update) (v4.2.0)

### Spectral Period

1.00 Second Spectral Acceleration

### Latitude

Decimal degrees

47.5567

### Time Horizon

Return period in years

210

### Longitude

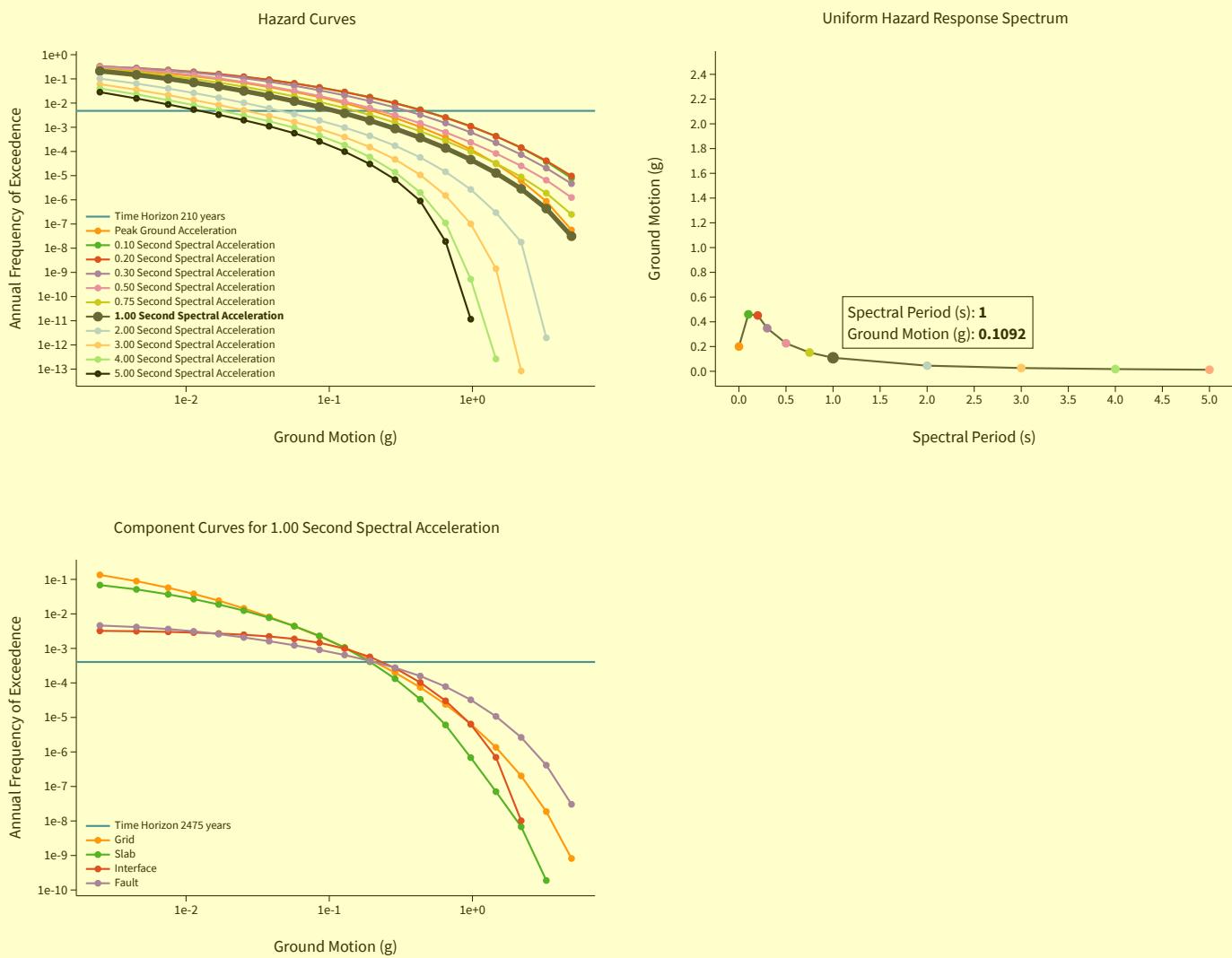
Decimal degrees, negative values for western longitudes

-122.19

### Site Class

760 m/s (B/C boundary)

^ Hazard Curve



[View Raw Data](#)

**Table 6-6** Values of Site Coefficient,  $F_v$ , for 1.0-sec Period Spectral Acceleration

Site Class	Mapped Spectral Acceleration Coefficient at Period 1.0 sec (S1)					
	$S1 \leq 0.1$	$S1 = 0.2$	$S1 = 0.3$	$S1 = 0.4$	$S1 = 0.5$	$S1 \geq 0.6$
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.8	0.8	0.8	0.8	0.8	0.8
C	1.5	1.5	1.5	1.5	1.5	1.4
D	2.4	2.2	2.0	1.9	1.8	1.7
E	4.2	3.3	2.8	2.4	2.2	2.0
F	*	*	*	*	*	*

\* Site-specific response geotechnical investigation and dynamic site response analysis should be considered,  
Note: Use straight line interpolation for intermediate values of  $S_1$ .

**S1 = 0.1092 g**  
**Fv = 2.382**

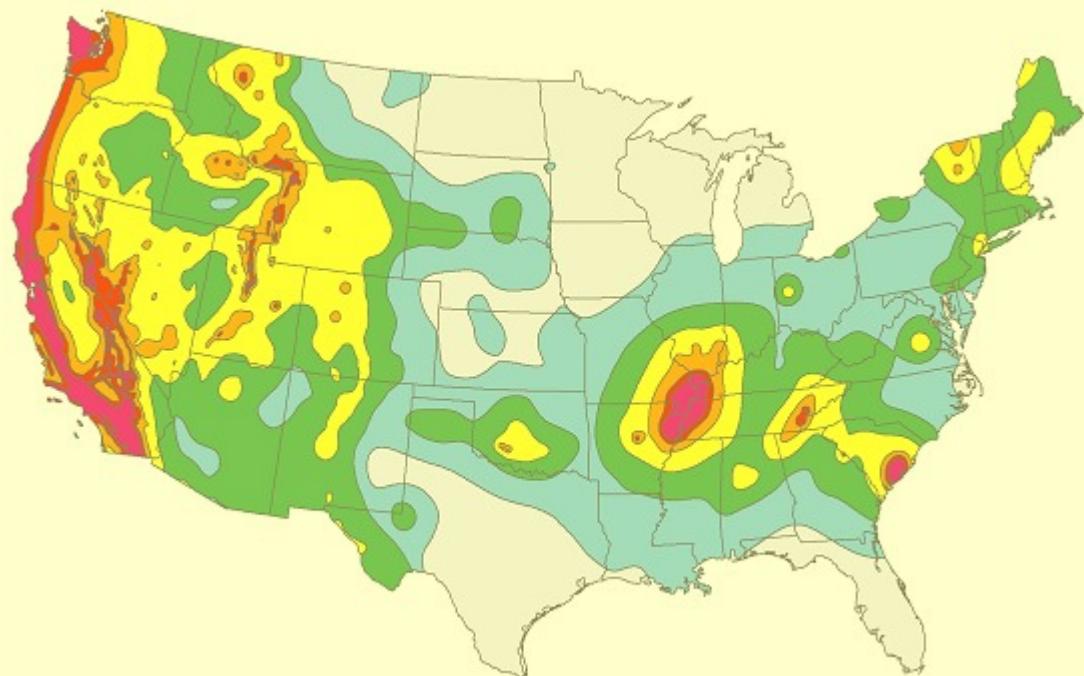
## Appendix A

## Section 0-3 - Spectra\_SEE = 1000 year return period parameters

**BEToolbox™***Spectra*

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Version 5.0.5 - Built on Aug 17 2020



**Appendix A****Section 0-3 - Spectra\_SEE = 1000 year return period parameters**

WSDOT Bridge Design Manual  
2014 Seismic Hazard Map, 7% probability of exceedance in 75 years

Site Coordinates (Latitude,Longitude): 47.5567° N, 122.19° W  
Site Soil Classification: Site Class D - Stiff Soil

Seismic hazard maps are for sites at the boundary of Site Classes B and C, which is  $\bar{v}_s = 2500 \text{ ft/s}$  (760 m/s). Adjustments for other Site Classes are made as needed.

Period (sec)	Sa (g)	
0.0	0.430	PGA - Site Class B/C Boundary
0.2	0.979	S <sub>s</sub> - Site Class B/C Boundary
1.0	0.283	S <sub>1</sub> - Site Class B/C Boundary

Values of Site Coefficient, F<sub>pga</sub>, for Peak Ground Acceleration

Site Class	Mapped Peak Ground Acceleration Coefficient (PGA)					
	PGA ≤ 0.10	PGA = 0.20	PGA = 0.30	PGA = 0.40	PGA = 0.50	PGA ≥ 0.60
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.9	0.9	0.9	0.9	0.9	0.9
C	1.3	1.2	1.2	1.2	1.2	1.2
D	1.6	1.4	1.3	1.2	1.1	1.1
E	2.4	1.9	1.6	1.4	1.2	1.1

For Site Class D, F<sub>pga</sub> = 1.170

Values for Site Coefficient, F<sub>a</sub>, for 0.2 sec Period Spectral Acceleration

Site Class	Mapped Spectral Acceleration Coefficient at Period 0.2 sec (S <sub>s</sub> )					
	S <sub>s</sub> ≤ 0.25	S <sub>s</sub> = 0.50	S <sub>s</sub> = 0.75	S <sub>s</sub> = 1.00	S <sub>s</sub> = 1.25	S <sub>s</sub> ≥ 1.50
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.9	0.9	0.9	0.9	0.9	0.9
C	1.3	1.3	1.2	1.2	1.2	1.2
D	1.6	1.4	1.2	1.1	1.0	1.0
E	2.4	1.7	1.3	1.0	0.9	0.9

For Site Class D, F<sub>a</sub> = 1.108

Values of Site Coefficient, F<sub>v</sub>, for 1.0 sec Period Spectral Acceleration

Site Class	Mapped Spectral Acceleration Coefficient at Period 1.0 sec (S <sub>1</sub> )					
	S <sub>1</sub> ≤ 0.1	S <sub>1</sub> = 0.2	S <sub>1</sub> = 0.3	S <sub>1</sub> = 0.4	S <sub>1</sub> = 0.5	S <sub>1</sub> ≥ 0.6
A	0.8	0.8	0.8	0.8	0.8	0.8
B	0.8	0.8	0.8	0.8	0.8	0.8
C	1.5	1.5	1.5	1.5	1.5	1.4
D	2.4	2.2	2.0	1.9	1.8	1.7
E	4.2	3.3	2.8	2.4	2.2	2.0

For Site Class D, F<sub>v</sub> = 2.034

$$\begin{aligned} A_s &= F_{\text{pga}} \text{ PGA} = (1.170)(0.430g) = 0.503g \\ S_{DS} &= F_a S_s = (1.108)(0.979g) = 1.085g \\ S_{D1} &= F_v S_1 = (2.034)(0.283g) = 0.576g \\ T_o &= 0.2T_s = (0.2)(0.530) = 0.106 \text{ sec} \\ T_s &= S_{D1}/S_{DS} = (0.576)/(1.085) = 0.530 \text{ sec} \end{aligned}$$

$$Kh = 1/2 \text{ PGA} = 1/2 As = 1/2 * 0.503 = 0.2515$$

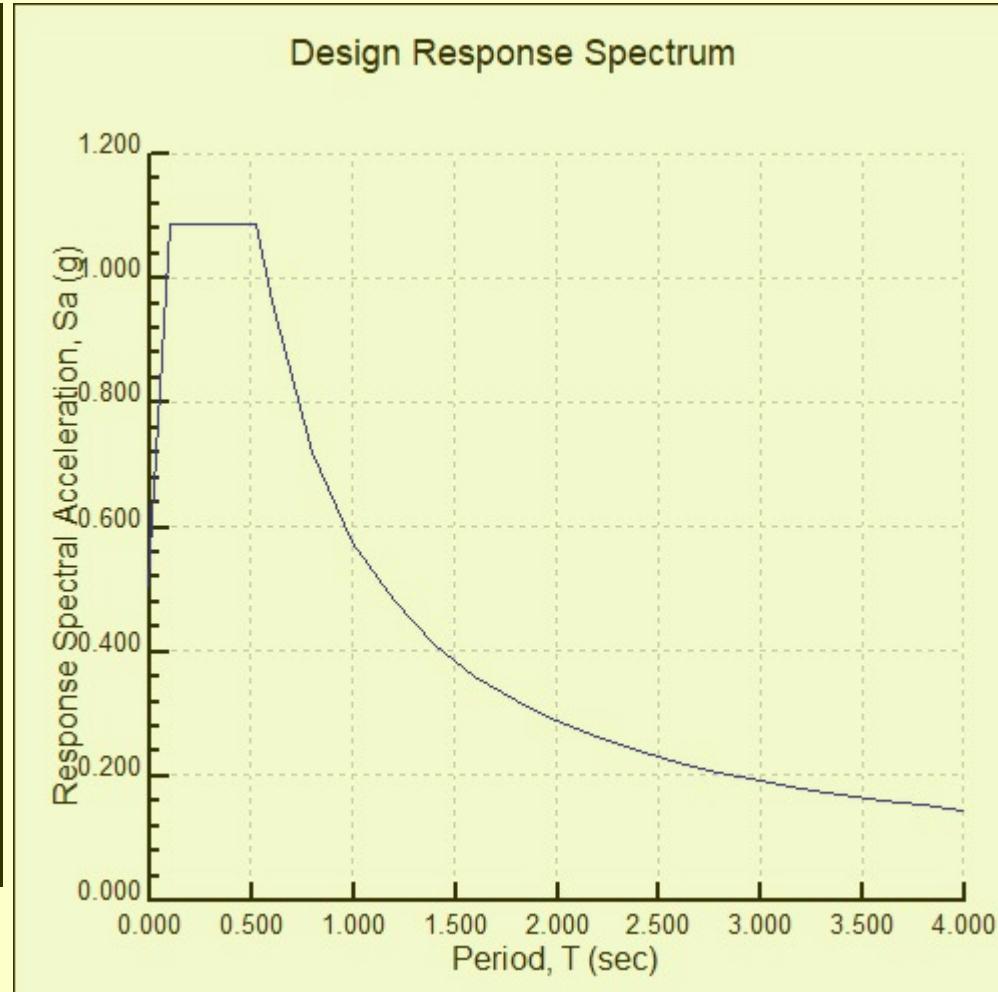
**Appendix A****Section 0-3 - Spectra\_SEE = 1000 year return period parameters**

Partitions for Seismic Design Categories A, B, C, and D

$S_{D1}$	SDC
$S_{D1} < 0.15$	A
$0.15 \leq S_{D1} < 0.30$	B
$0.30 \leq S_{D1} < 0.50$	C
$0.50 \leq S_{D1}$	D

Seismic Design Category (SDC) = D

Period, T (sec)	$S_a$ (g)
0.000	0.503
0.106	1.085 $T_o$
0.200	1.085
0.400	1.085
0.530	1.085 $T_s$
0.600	0.959
0.800	0.719
1.000	0.576
1.200	0.480
1.400	0.411
1.600	0.360
1.800	0.320
2.000	0.288
2.200	0.262
2.400	0.240
2.600	0.221
2.800	0.206
3.000	0.192
3.200	0.180
3.400	0.169
3.600	0.160
3.800	0.151
4.000	0.144



## Appendix A

### Section 0-4 - Fine Soils Liquefaction

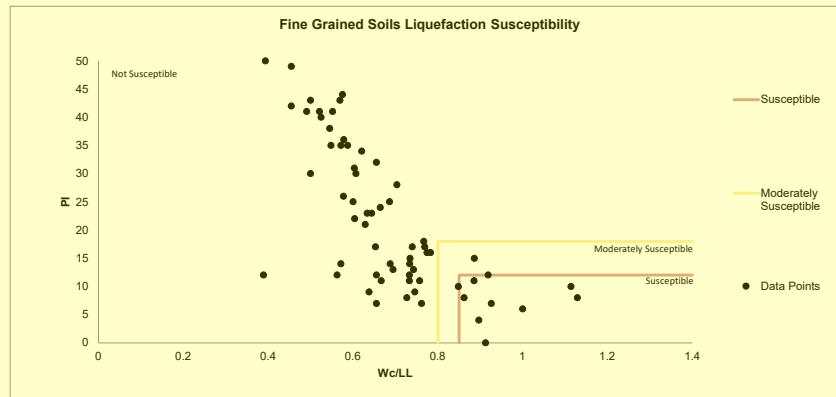
Direct Input  
Calculation Cell

Boring	Depth (feet)	LL	Wc (%)	PI	Wc/LL	Adjusted PI	Susceptible?
W-148	12.5	29	18.5	9	0.64	9	No
W-148	20.2	24	21.9	NP	0.91	0	No
W-148	35.0	75	29.5	50	0.39	50	No
W-148	45.0	65	31.9	41	0.49	41	No
W-148	61.9	38	27.9	14	0.73	14	No
W-148	75.0	48	31.9	24	0.66	24	No
W-148	92.0	38	23.9	21	0.63	21	No
W-148	110.0	33	24.0	8	0.73	8	No
W-148	120.0	34	29.3	8	0.86	8	Yes
R2B-68	7.0	73	42.0	44	0.58	44	No
R2B-68	13.0	76	38.0	30	0.50	30	No
R2B-68	24.0	66	36.0	38	0.55	38	No
R2B-68	59.0	33	33.0	6	1.00	6	Yes
R2B-68	69.0	39	30.0	17	0.77	17	No
R2B-68	84.0	33	25.0	11	0.76	11	No
R2B-68	94.0	27	25.0	7	0.93	7	Yes
R2B-68	109.0	29	19.0	7	0.66	7	No
R2B-69	3.0	72	41.0	43	0.57	43	No
R2B-69	6.0	71	37.0	41	0.52	41	No
R2B-69	10.0	67	37.0	41	0.55	41	No
R2B-69	13.0	58	35.0	31	0.60	31	No
R2B-69	27.0	51	35.0	25	0.69	25	No
R2B-69	33.0	54	38.0	28	0.70	28	No
R2B-69	38.0	72	36.0	43	0.50	43	No
R2B-69	58.0	35	31.0	11	0.89	11	Yes
R2B-69	78.0	58	38.0	32	0.66	32	No
R2B-69	83.0	35	26.0	13	0.74	13	No
R2B-69	93.0	30	22.0	11	0.73	11	No
R2B-69	98.0	32	22.0	14	0.69	14	No
R2B-69	108.0	32	18.0	12	0.56	12	No
R2B-71	7.0	44	39.0	15	0.89	15	Moderately
R2B-71	29.0	70	40.0	35	0.57	35	No
R2B-71	44.0	58	36.0	34	0.62	34	No
R2B-71	54.0	60	36.0	25	0.60	25	No
R2B-71	74.0	36	25.0	13	0.69	13	No
R2B-71	79.0	31	35.0	8	1.13	8	Yes
W-147	5.0	37	27.6	9	0.75	9	No
W-147	7.5	49	32.0	17	0.65	17	No
W-147	10.0	31	27.8	4	0.90	4	Yes
W-147	15.0	77	35.0	42	0.45	42	No
W-147	20.0	79	35.9	49	0.45	49	No
W-147	25.0	79	34.0	53	0.43	53	No
W-147	30.0	84	38.8	53	0.46	53	No
W-147	45.0	68	35.7	40	0.53	40	No
W-147	70.0	48	30.4	23	0.63	23	No
W-147	80.0	28	16.0	14	0.57	14	No
W-147	85.0	41	32.1	16	0.78	16	No
W-147	90.0	43	33.0	18	0.77	18	No
W-147	100.0	40	29.6	17	0.74	17	No
W-147	110.0	35	25.7	15	0.73	15	No
R2B-70	6.0	33	28.0	10	0.85	10	Moderately
R2B-70	13.0	37	34.0	12	0.92	12	Moderately
R2B-70	28.0	63	37.0	35	0.59	35	No
R2B-70	38.0	64	37.0	36	0.58	36	No
R2B-70	48.0	56	34.0	30	0.61	30	No
R2B-70	63.0	48	29.0	22	0.60	22	No
R2B-70	68.0	40	31.0	16	0.78	16	No
R2B-70	78.0	30	20.0	11	0.67	11	No
R2B-70	88.0	62	34.0	35	0.55	35	No
R2B-70	98.0	35	39.0	10	1.11	10	Yes
R2B-70	108.0	36	14.0	12	0.39	12	No
R2B-70	123.0	30	22.0	12	0.73	12	No
R2B-72	39.0	45	26.0	26	0.58	26	No
R2B-72	49.0	29	19.0	12	0.66	12	No
R2B-72	79.0	45	29.0	23	0.64	23	No
R2B-72	99.0	21	16.0	7	0.76	7	No

Moderate Susceptibility Limits	
Wc/LL	PI
0.8	0
0.8	18
1.4	18

Susceptibility Limits	
Wc/LL	PI
0.85	0
0.85	12
1.4	12

Susceptibility Breakdown for Data Set	
% Susceptible:	7
% Moderately Susceptible:	3
% Moderately or Susceptible:	10



## Appendix A

### Section 1-1 - Kp ESU 3B - Log Spiral

Calculation of passive earth pressure coefficient  $K_{pq}$  using the log-spiral slip surface

Note: Solver logic limits  $K_p$  to between 1 and 50 (cell C36)

\*From Soubra and Macuh (2002) "Active and Passive EP Coeff by a Kinematic Approach" Geotechnical Engr 155(2) 119-131.

	<u>Input Data</u>	
Soil Friction	$\phi$	(°) 34 (rad) 0.593412
Wall Friction	$\delta$	22.66667 0.395608
wall angle	$\lambda$	0 0
backfill angle	$\beta$	0 0

	<u>Unknowns</u>	
	(rad)	(°)
$\theta_0$	0.561655	32.18049
$\theta_1$	1.349632	77.3282

	<u>Result</u>	
$K_{pq}$	7.30827	
$\gamma_{eq}$	840.4511 pcf	Above GWT
$\gamma_{eq}$	384.415 pcf	Below GWT

$$P_p = \frac{1}{2} K_{pq} \gamma l^2 + K_{pq} q l + K_{pc} c l$$

where  $l$  = wall length =  $\frac{H}{\cos \lambda}$

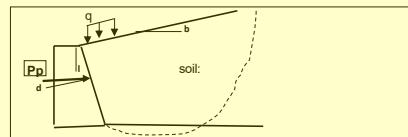
$\lambda$	0	degrees
H	10.5	ft
I	10.5	ft
$\gamma_{soil}$	115	pcf
cohesion	0	psf
surcharge	0	psf
		0

$K_{pq}$  7.30827      <---- If you have no surcharge or cohesion, this is your  $K_p$   
 $K_{pc}$   
 $K_{pq}$

Pp= 42751.46 lb/ft

Horiz. Pp= 42.75 kips/linear foot of wall

!!! Use Solver with the already-programmed constraints to minimize C19 !!!



Instructions for use:

1. Input your data (only change the numbers in blue!!)
  2. Go to cell C19 and change the function to whichever K you are interested in obtaining (Kpp = Kpq, etc.) Make sure you leave the cell selected. Also, just change the 'K...' part - don't change the cell references.
  3. Go to 'Tools', then 'Solver...', then click 'Solve'.....the constraints should already be entered. If the constraints are not entered, refer to the handout to re-enter them.
  4. Once you have your K's, plug into equation shown to the left to obtain the total passive force Pp.
- \* If 'Solver' does not appear in the tools menu, go to 'Add-ins' and add it to your tools. Also, you may find it more convenient to hot-key 'solver'....Alt-t then 'Enter'

The different commands for the K functions are:  
 $K_{pq}$  .....for  $K_{p\_gamma}$   
 $K_{pc}$  .....for  $K_{p\_cohesion}$   
 $K_{pq}$  .....for  $K_{p\_surcharge}$

## Appendix A

### Section 1-2 - Kp Gravel Borrow - Log Spiral

#### Calculation of passive earth pressure coefficient $K_{pq}$ using the log-spiral slip surface

Note: Solver logic limits Kp to between 1 and 50 (cell C36)

\*From Soubra and Macuh (2002) "Active and Passive EP Coeff by a Kinematic Approach" Geotechnical Engr 155(2) 119-131.

Input Data		
	(°)	(rad)
Soil Friction	38	0.663225
Wall Friction	25.33333	0.44215
wall angle	0	0
backfill angle	0	0

Unknowns		
	(rad)	(°)
$\theta_0$	0.558878	32.02138
$\theta_1$	1.389403	79.60694

Result	
$K_{pq}$	10.38662
$\gamma_{eq}$	363.5317 pcf
$\gamma_{eq}$	-284.593 pcf
	Above GWT
	Below GWT

$$P_p = \frac{1}{2} K_{pq} \gamma l^2 + K_{pq} q l + K_{pc} c l$$

where  $l$  = wall length =  $\frac{H}{\cos \lambda}$

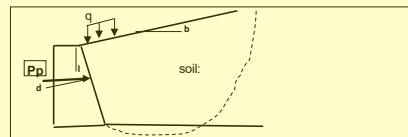
$\lambda$	0	degrees
H	10.5	ft
I	10.5	ft
$\gamma_{soil}$	35	pcf
cohesion	0	psf
surcharge	0	psf
		0

$K_{pq}$	10.38662	<---- If you have no surcharge or cohesion, this is your Kp
$K_{pc}$		
$K_{pq}$		

$P_p = 18112.55 \text{ lb/ft}$

Horiz.  $P_p = 18.11 \text{ kips/linear foot of wall}$

!!! Use Solver with the already-programmed constraints to minimize C19 !!!



#### Instructions for use:

1. Input your data (only change the numbers in blue!!)
  2. Go to cell C19 and change the function to whichever K you are interested in obtaining (Kpp = Kpq, etc.) Make sure you leave the cell selected. Also, just change the 'K...' part - don't change the cell references.
  3. Go to 'Tools', then 'Solver...', then click 'Solve'.....the constraints should already be entered. If the constraints are not entered, refer to the handout to re-enter them.
  4. Once you have your K's, plug into equation shown to the left to obtain the total passive force Pp.
- \* If 'Solver' does not appear in the tools menu, go to 'Add-ins' and add it to your tools. Also, you may find it more convenient to hot-key 'solver'....Alt-t then 'v' then 'Enter'

The different commands for the K functions are:  
 $K_{pq}$  .....for  $K_{pq\_gamma}$   
 $K_{pc}$  .....for  $K_{pc\_cohesion}$   
 $K_{pp}$  .....for  $K_{pp\_surcharge}$

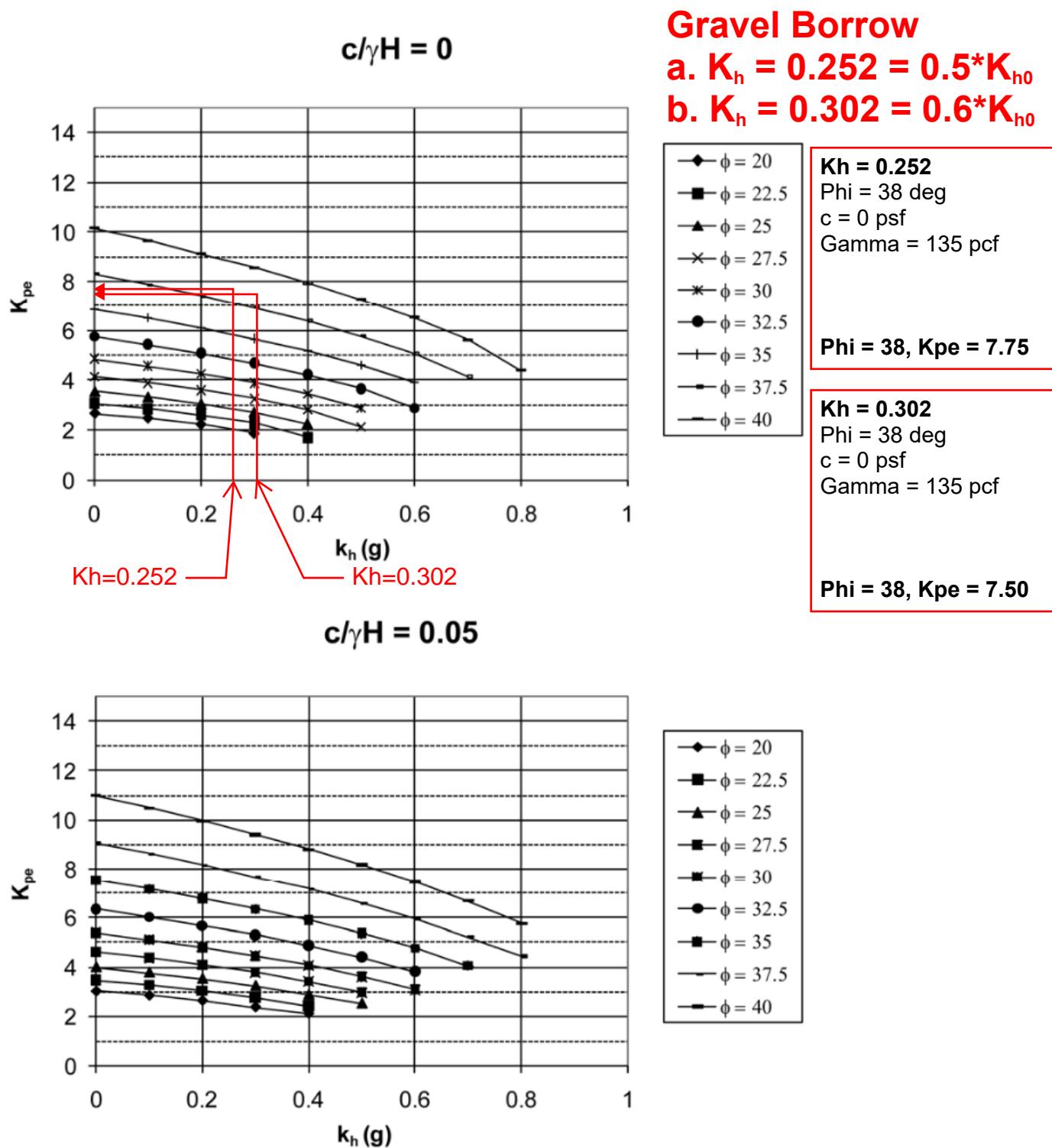


Figure A11.4-2—Seismic Passive Earth Pressure Coefficient Based on Log Spiral Procedure for  $c/\gamma H = 0$  and  $0.05$  ( $c$  = soil cohesion,  $\gamma$  = soil unit weight, and  $H$  = height or depth of wall over which the passive resistance acts)

Note:  $k_h = A_s = k_{ho}$  for wall heights greater than 20.0 ft.

# Appendix A

## Section 2-1 - Gravel Borrow - 0.5\*Kh

### Mononobe-Okabe Method (M-O)

Pseudo-static analysis of seismic earth pressure on retaining structures

Job Name: I-405 R2B

Job Number: 19047-04

#### NOTES:

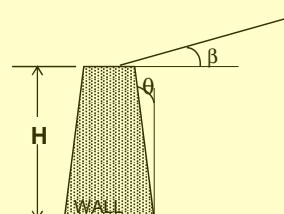
- (1) Refer to Geotechnical Earthquake Engineering by Kramer before using
- (2) Refer to Sections 11.5 & 11.6, 11.8.1.1, and Figure 11.11 a (Kramer)
- Note: 1/3 to 1/2 peak ground surface accelerations are typically used in M-O equation (see Kramer Sect. 11.8.1.1, p. 494)
- $k_v$  can be assumed =0 when using M-O method for typ. wall designs (Seed and Whitman ,1970; see Kramer p. 479)
- (3) This method does not include a water table.
- (4) This method is only recommended as a rough estimate for tiebacks.
- (5) Check with hand calculations.
- (6) Insert values into yellow areas.
- (7) This method assumes a "Yielding" wall condition
- (8) Paper: "Seismic Design and Behavior of Gravity Retaining Walls" by Robt. V. Whitman(1990)

Parameters	Symbol	Value	Units
Slope Inclination	$\beta$	0.000	radians
Horizontal Acceleration coef/g	$k_h$	0.252	
Vertical Acceleration coef/g	$k_v$	0	
Soil Friction Angle	$\phi$	0.663	radians
Soil/Wall Friction Angle	$\delta$	0.442	radians
Wall Angle (Batter) from Vertical	$\theta$	0.000	radians
Unit Weight	$\gamma$	115	pcf
Height of Wall	$H$	10.5	feet

Conversion from degrees to radians:

Degrees	Radians	Reference	
0	0.0000	Slope	$\beta$
		1.5H:1V	33.7
		1.75H:1V	29.7
38	0.6632	2H:1V	26.6
25.333	0.4422	2.5H:1V	21.8
0.0	0.0000	3H:1V	18.4
		3.5H:1V	15.9
		4H:1V	14.0
		5H:1V	11.3
		10H:1V	5.7

To be calculated	Symbol	Value
Coeff. of Active Earth Pressure	$K_a$	calculated
Active earth pressure resultant	$P_a$	calculated
Total Lateral Force	$P_{ae}$	calculated
Dynamic Active Earth Pressure	$K_{ae}$	calculated
Total thrust acts at this height:	$h$	calculated
Critical Failure Surface from Horz.	$\alpha_{ea}$	calculated



#### Active Earth Pressure Calculations

Active Earth Pressure Coefficient	$K_a$	=	0.217
Active thrust static component	$P_a$	=	1374 pounds/foot
$\text{ArcTan}(kh/(1-kv)) =$	$\psi$	=	0.2469 radians = 14.1 degrees
Dynamic active earth press. coef.	$K_{ae}$	=	0.394
Total Active Thrust	$P_{ae}$	=	2497 pounds/foot
Active thrust dynamic component	$\Delta P_{ae}$	=	1123 pounds/foot
Total Active Thrust acts at:	$h$	=	4.8 feet
Overturning moment about base	$M_o$	=	10742 ft-lb/ft

Static Equivalent Active Fluid Unit Weight = 25 pcf

14.1 degrees

Dynamic Equivalent Active Fluid Unit Weight = 45 pcf

Dynamic Uniform Lateral Surcharge = 107 psf or = 10.2H

Note: The dynamic portion of the equivalent fluid unit weight is typically applied as a rectangular distribution rather than a triangular distribution.

The above calculations correspond to a critical failure surface angle of	$C1E$	1.85
	$C2E$	3.23
	$\alpha_{EA}$	= 0.828 radians = 47 degrees above horizontal

Static conditions produce a critical failure surface angle of	$\alpha_s$	= 1.117 radians = 64 degrees above horizontal
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#### Passive Earth Pressure Calculations

Passive Earth Pressure Coefficient	$K_p$	= 14.22074 (Coulomb)
Passive thrust static component	$P_p$	= 90151 pounds/foot
Dynamic passive earth press. coef	$K_{pe}$	= 11.21
Total Passive Thrust	$P_{pe}$	= 71070 pounds/foot
Passive thrust dynamic component	$\Delta P_{pe}$	= -19081 pounds/foot

Static Equivalent Passive Fluid Unit Weight = 1635 pcf

Dynamic Equivalent Passive Fluid Unit Weight = 1289 pcf

The above calculations correspond to a critical failure surface angle of	$C3E$	1.85
	$C4E$	3.23
	$\alpha_{pe}$	= 0.35 radians = 20 degrees above horizontal

According to Ref. (8), experimental investigation found good agreement with Wood's theory (applicable to "Non-Yielding" walls), while the measured forces exceeded by a factor of 2 to 3 those predicted by the Mononobe-Okabe (M-O) equation (which is applicable to "Yielding" walls). Therefore, in the case of a "Non-Yielding" wall, Ref. (8) would suggest using an "X" value of 2 to 3 times the above X value obtained for a "Yielding" wall.

Based on this approach, the recommendation in the report might read: " To account for short-term increases in lateral loads on subgrade walls due to seismic forces, apply a pressure (rectangular pressure distribution) equal to  $XH$  for yielding walls and (a value between  $2XH$  and  $3XH$ ) for non-yielding walls. This pressure is in addition to the static lateral pressure."

# Appendix A

## Section 2-2 - Gravel Borrow - 0.6\*Kh

### Mononobe-Okabe Method (M-O)

Pseudo-static analysis of seismic earth pressure on retaining structures

Job Name: I-405 R2B

Job Number: 19047-04

#### NOTES:

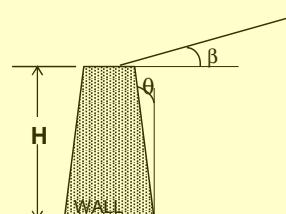
- (1) Refer to Geotechnical Earthquake Engineering by Kramer before using
- (2) Refer to Sections 11.5 & 11.6, 11.8.1.1, and Figure 11.11 a (Kramer)
- Note: 1/3 to 1/2 peak ground surface accelerations are typically used in M-O equation (see Kramer Sect. 11.8.1.1, p. 494)
- $k_v$  can be assumed =0 when using M-O method for typ. wall designs (Seed and Whitman ,1970; see Kramer p. 479)
- (3) This method does not include a water table.
- (4) This method is only recommended as a rough estimate for tiebacks.
- (5) Check with hand calculations.
- (6) Insert values into yellow areas.
- (7) This method assumes a "Yielding" wall condition
- (8) Paper: "Seismic Design and Behavior of Gravity Retaining Walls" by Robt. V. Whitman(1990)

Parameters	Symbol	Value	Units
Slope Inclination	$\beta$	0.000	radians
Horizontal Acceleration coef/g	$k_h$	0.302	
Vertical Acceleration coef/g	$k_v$	0	
Soil Friction Angle	$\phi$	0.663	radians
Soil/Wall Friction Angle	$\delta$	0.442	radians
Wall Angle (Batter) from Vertical	$\theta$	0.000	radians
Unit Weight	$\gamma$	115	pcf
Height of Wall	H	10.5	feet

Conversion from degrees to radians:

Degrees	Radians	Reference	
0	0.0000	Slope	$\beta$
		1.5H:1V	33.7
		1.75H:1V	29.7
38	0.6632	2H:1V	26.6
25.333	0.4422	2.5H:1V	21.8
0.0	0.0000	3H:1V	18.4
		3.5H:1V	15.9
		4H:1V	14.0
		5H:1V	11.3
		10H:1V	5.7

To be calculated	Symbol	Value
Coeff. of Active Earth Pressure	$K_a$	calculated
Active earth pressure resultant	$P_a$	calculated
Total Lateral Force	$P_{ae}$	calculated
Dynamic Active Earth Pressure	$K_{ae}$	calculated
Total thrust acts at this height:	$h$	calculated
Critical Failure Surface from Horz.	$\alpha_{ea}$	calculated



#### Active Earth Pressure Calculations

Active Earth Pressure Coefficient	$K_a$	=	0.217
Active thrust static component	$P_a$	=	1374 pounds/foot
$\text{ArcTan}(k_h/(1-k_v)) =$	$\psi$	=	0.2933 radians = 16.8 degrees
Dynamic active earth press. coef.	$K_{ae}$	=	0.444
Total Active Thrust	$P_{ae}$	=	2817 pounds/foot
Active thrust dynamic component	$\Delta P_{ae}$	=	1443 pounds/foot
Total Active Thrust acts at:	$h$	=	4.9 feet
Overturining moment about base	$M_o$	=	12562 ft-lb/ft

Static Equivalent Active Fluid Unit Weight = 25 pcf

16.8 degrees

Dynamic Equivalent Active Fluid Unit Weight = 51 pcf

Dynamic Uniform Lateral Surcharge = 137 psf or = 13.1H

Note: The dynamic portion of the equivalent fluid unit weight is typically applied as a rectangular distribution rather than a triangular distribution.

The above calculations correspond to a critical failure surface angle of	$C1E$	1.96
	$C2E$	3.68
	$\alpha_{EA}$	= 0.773 radians = 44 degrees above horizontal

Static conditions produce a critical failure surface angle of	$\alpha_s$	= 1.117 radians = 64 degrees above horizontal
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#### Passive Earth Pressure Calculations

Passive Earth Pressure Coefficient	$K_p$	= 14.22074 (Coulomb)
Passive thrust static component	$P_p$	= 90151 pounds/foot
Dynamic passive earth press. coef	$K_{pe}$	= 10.60
Total Passive Thrust	$P_{pe}$	= 67187 pounds/foot
Passive thrust dynamic component	$\Delta P_{pe}$	= -22963 pounds/foot

Static Equivalent Passive Fluid Unit Weight = 1635 pcf

Dynamic Equivalent Passive Fluid Unit Weight = 1219 pcf

The above calculations correspond to a critical failure surface angle of	$C3E$	1.96
	$C4E$	3.68
	$\alpha_{pe}$	= 0.37 radians = 21 degrees above horizontal

According to Ref. (8), experimental investigation found good agreement with Wood's theory (applicable to "Non-Yielding" walls), while the measured forces exceeded by a factor of 2 to 3 those predicted by the Mononobe-Okabe (M-O) equation (which is applicable to "Yielding" walls). Therefore, in the case of a "Non-Yielding" wall, Ref. (8) would suggest using an "X" value of 2 to 3 times the above X value obtained for a "Yielding" wall.

Based on this approach, the recommendation in the report might read: " To account for short-term increases in lateral loads on subgrade walls due to seismic forces, apply a pressure (rectangular pressure distribution) equal to  $XH$  for yielding walls and (a value between  $2XH$  and  $3XH$ ) for non-yielding walls. This pressure is in addition to the static lateral pressure."

**Mononobe-Okabe Method (M-O)**

Pseudo-static analysis of seismic earth pressure on retaining structures

Job Name: I-405 R2B

Job Number: 19047-04

**NOTES:**

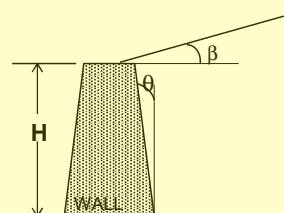
- (1) Refer to Geotechnical Earthquake Engineering by Kramer before using
- (2) Refer to Sections 11.5 & 11.6, 11.8.1.1, and Figure 11.11 a (Kramer)
- Note: 1/3 to 1/2 peak ground surface accelerations are typically used in M-O equation (see Kramer Sect. 11.8.1.1, p. 494)
- $k_v$  can be assumed =0 when using M-O method for typ. wall designs (Seed and Whitman ,1970; see Kramer p. 479)
- (3) This method does not include a water table.
- (4) This method is only recommended as a rough estimate for tiebacks.
- (5) Check with hand calculations.
- (6) Insert values into yellow areas.
- (7) This method assumes a "Yielding" wall condition
- (8) Paper: "Seismic Design and Behavior of Gravity Retaining Walls" by Robt. V. Whitman(1990)

Parameters	Symbol	Value	Units
Slope Inclination	$\beta$	0.000	radians
Horizontal Acceleration coef/g	$k_h$	0.252	
Vertical Acceleration coef/g	$k_v$	0	
Soil Friction Angle	$\phi$	0.593	radians
Soil/Wall Friction Angle	$\delta$	0.396	radians
Wall Angle (Batter) from Vertical	$\theta$	0.000	radians
Unit Weight	$\gamma$	115	pcf
Height of Wall	H	10.5	feet

Conversion from degrees to radians:

Degrees	Radians	Reference	
0	0.0000	Slope	$\beta$
		1.5H:1V	33.7
		1.75H:1V	29.7
34	0.5934	2H:1V	26.6
22.667	0.3956	2.5H:1V	21.8
0.0	0.0000	3H:1V	18.4
		3.5H:1V	15.9
		4H:1V	14.0
		5H:1V	11.3
		10H:1V	5.7

To be calculated	Symbol	Value
Coeff. of Active Earth Pressure	$K_a$	calculated
Active earth pressure resultant	$P_a$	calculated
Total Lateral Force	$P_{ae}$	calculated
Dynamic Active Earth Pressure	$K_{ae}$	calculated
Total thrust acts at this height:	$h$	calculated
Critical Failure Surface from Horz.	$\alpha_{ea}$	calculated

**Active Earth Pressure Calculations**

Active Earth Pressure Coefficient	$K_a$	=	0.254
Active thrust static component	$P_a$	=	1612 pounds/foot
$\text{ArcTan}(k_h/(1-k_v)) =$	$\psi$	=	0.2469 radians = 14.1 degrees
Dynamic active earth press. coef.	$K_{ae}$	=	0.448
Total Active Thrust	$P_{ae}$	=	2838 pounds/foot
Active thrust dynamic component	$\Delta P_{ae}$	=	1226 pounds/foot
Total Active Thrust acts at:	$h$	=	4.7 feet
Overturning moment about base	$M_o$	=	12335 ft-lb/ft

Static Equivalent Active Fluid Unit Weight = 29 pcf

14.1 degrees

Dynamic Equivalent Active Fluid Unit Weight = 51 pcf  
Dynamic Uniform Lateral Surcharge = 117 psf or = 11.1H

Note: The dynamic portion of the equivalent fluid unit weight is typically applied as a rectangular distribution rather than a triangular distribution.

The above calculations correspond to a critical failure surface angle of	$C1E$	1.86
	$C2E$	3.34
	$\alpha_{EA}$	= 0.769 radians = 44 degrees above horizontal

Static conditions produce a critical failure surface angle of	$\alpha_s$	= 1.082 radians = 62 degrees above horizontal
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**Passive Earth Pressure Calculations**

Passive Earth Pressure Coefficient	$K_p$	= 8.951997 (Coulomb)
Passive thrust static component	$P_p$	= 56750 pounds/foot
Dynamic passive earth press. coef	$K_{pe}$	= 6.96
Total Passive Thrust	$P_{pe}$	= 44117 pounds/foot
Passive thrust dynamic component	$\Delta P_{pe}$	= -12633 pounds/foot

Static Equivalent Passive Fluid Unit Weight = 1029 pcf

Dynamic Equivalent Passive Fluid Unit Weight = 800 pcf

The above calculations correspond to a critical failure surface angle of	$C3E$	1.86
	$C4E$	3.34
	$\alpha_{pe}$	= 0.38 radians = 22 degrees above horizontal

According to Ref. (8), experimental investigation found good agreement with Wood's theory (applicable to "Non-Yielding" walls), while the measured forces exceeded by a factor of 2 to 3 those predicted by the Mononobe-Okabe (M-O) equation (which is applicable to "Yielding" walls). Therefore, in the case of a "Non-Yielding" wall, Ref. (8) would suggest using an "X" value of 2 to 3 times the above X value obtained for a "Yielding" wall.

Based on this approach, the recommendation in the report might read: " To account for short-term increases in lateral loads on subgrade walls due to seismic forces, apply a pressure (rectangular pressure distribution) equal to  $XH$  for yielding walls and (a value between  $2XH$  and  $3XH$ ) for non-yielding walls. This pressure is in addition to the static lateral pressure."

# Appendix A

## Section 2-4 - ESU 3B - 0.6\*Kh

### Mononobe-Okabe Method (M-O)

Pseudo-static analysis of seismic earth pressure on retaining structures

Job Name: I-405 R2B

Job Number: 19047-04

#### NOTES:

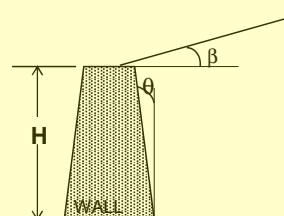
- (1) Refer to Geotechnical Earthquake Engineering by Kramer before using
- (2) Refer to Sections 11.5 & 11.6, 11.8.1.1, and Figure 11.11 a (Kramer)
- Note: 1/3 to 1/2 peak ground surface accelerations are typically used in M-O equation (see Kramer Sect. 11.8.1.1, p. 494)  
kv can be assumed =0 when using M-O method for typ. wall designs (Seed and Whitman ,1970; see Kramer p. 479)
- (3) This method does not include a water table.
- (4) This method is only recommended as a rough estimate for tiebacks.
- (5) Check with hand calculations.
- (6) Insert values into yellow areas.
- (7) This method assumes a "Yielding" wall condition
- (8) Paper: "Seismic Design and Behavior of Gravity Retaining Walls" by Robt. V. Whitman(1990)

Parameters	Symbol	Value	Units
Slope Inclination	$\beta$	0.000	radians
Horizontal Acceleration coef/g	$k_h$	0.302	
Vertical Acceleration coef/g	$k_v$	0	
Soil Friction Angle	$\phi$	0.593	radians
Soil/Wall Friction Angle	$\delta$	0.396	radians
Wall Angle (Batter) from Vertical	$\theta$	0.000	radians
Unit Weight	$\gamma$	115	pcf
Height of Wall	H	10.5	feet

Conversion from degrees to radians:

Degrees	Radians	Reference	
0	0.0000	Slope	$\beta$
		1.5H:1V	33.7
		1.75H:1V	29.7
34	0.5934	2H:1V	26.6
22.667	0.3956	2.5H:1V	21.8
0.0	0.0000	3H:1V	18.4
		3.5H:1V	15.9
		4H:1V	14.0
		5H:1V	11.3
		10H:1V	5.7

To be calculated	Symbol	Value
Coeff. of Active Earth Pressure	$K_a$	calculated
Active earth pressure resultant	$P_a$	calculated
Total Lateral Force	$P_{ae}$	calculated
Dynamic Active Earth Pressure	$K_{ae}$	calculated
Total thrust acts at this height:	$h$	calculated
Critical Failure Surface from Horz.	$\alpha_{ea}$	calculated



#### Active Earth Pressure Calculations

Active Earth Pressure Coefficient	$K_a$	=	0.254
Active thrust static component	$P_a$	=	1612 pounds/foot
$\text{ArcTan}(k_h/(1-k_v)) =$	$\psi$	=	0.2933 radians = 16.8 degrees
Dynamic active earth press. coef.	$K_{ae}$	=	0.504
Total Active Thrust	$P_{ae}$	=	3194 pounds/foot
Active thrust dynamic component	$\Delta P_{ae}$	=	1582 pounds/foot
Total Active Thrust acts at:	$h$	=	4.9 feet
Overturning moment about base	$M_o$	=	14402 ft-lb/ft

Static Equivalent Active Fluid Unit Weight = 29 pcf

16.8 degrees

Dynamic Equivalent Active Fluid Unit Weight = 58 pcf

Dynamic Uniform Lateral Surcharge = 151 psf or = 14.3H

Note: The dynamic portion of the equivalent fluid unit weight is typically applied as a rectangular distribution rather than a triangular distribution.

The above calculations correspond to a critical failure surface angle of	$C1E$	2.00
	$C2E$	3.92
	$\alpha_{EA}$	= 0.708 radians = 41 degrees above horizontal

Static conditions produce a critical failure surface angle of	$\alpha_s$	= 1.082 radians = 62 degrees above horizontal
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#### Passive Earth Pressure Calculations

Passive Earth Pressure Coefficient	$K_p$	= 8.951997 (Coulomb)
Passive thrust static component	$P_p$	= 56750 pounds/foot
Dynamic passive earth press. coef	$K_{pe}$	= 6.55
Total Passive Thrust	$P_{pe}$	= 41498 pounds/foot
Passive thrust dynamic component	$\Delta P_{pe}$	= -15252 pounds/foot

Static Equivalent Passive Fluid Unit Weight = 1029 pcf

Dynamic Equivalent Passive Fluid Unit Weight = 753 pcf

The above calculations correspond to a critical failure surface angle of	$C3E$	2.00
	$C4E$	3.92
	$\alpha_{pe}$	= 0.39 radians = 22 degrees above horizontal

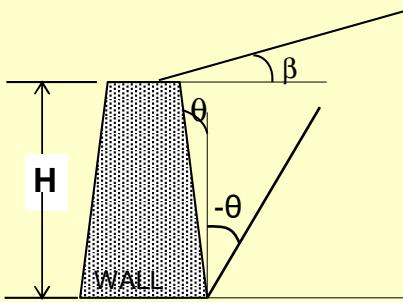
According to Ref. (8), experimental investigation found good agreement with Wood's theory (applicable to "Non-Yielding" walls), while the measured forces exceeded by a factor of 2 to 3 those predicted by the Mononobe-Okabe (M-O) equation (which is applicable to "Yielding" walls). Therefore, in the case of a "Non-Yielding" wall, Ref. (8) would suggest using an "X" value of 2 to 3 times the above X value obtained for a "Yielding" wall.

Based on this approach, the recommendation in the report might read: " To account for short-term increases in lateral loads on subgrade walls due to seismic forces, apply a pressure (rectangular pressure distribution) equal to  $XH$  for yielding walls and (a value between  $2XH$  and  $3XH$ ) for non-yielding walls. This pressure is in addition to the static lateral pressure."

## Documentation for LDCC Minimum Width Required to Resist Active Earth Pressure of Soil Behind the LDCC

The following calculation spreadsheets present our active earth pressure coefficient calculations for ESU 3B, based on Mononobe-Okabe methods. ESU 3B is the primary soil present behind the LDCC mass. Active earth pressure coefficients were calculated for varying LDCC batter angles, which correspond to  $\theta$  on the calculation spreadsheet (see figure below for reference). The batter angle of the LDCC mass corresponds to negative  $\theta$  angles, and a vertical LDCC face corresponds to a  $\theta$  angle of 0 degrees.

The maximum active earth pressure coefficient we calculated occurs at a vertical face of the LDCC, and reduces with increasing LDCC batter angle based on Monobe-Okabe methods.



## Appendix A

### Section 2-5 - ESU 3B - Varying LDCC Batter Angles

#### Seismic Active Lateral Earth Pressure Coefficient, $K_a$ for ESU 3B

#### Mononobe-Okabe Method (M-O)

Pseudo-static analysis of seismic earth pressure on retaining structures

Job Name: I-405 R2B

Job Number: 19047-04

#### NOTES:

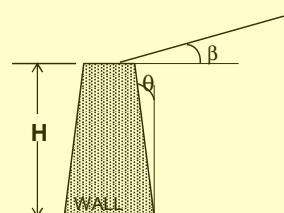
- (1) Refer to Geotechnical Earthquake Engineering by Kramer before using
- (2) Refer to Sections 11.5 & 11.6, 11.8.1.1, and Figure 11.11 a (Kramer)
- Note: 1/3 to 1/2 peak ground surface accelerations are typically used in M-O equation (see Kramer Sect. 11.8.1.1, p. 494)
- $k_v$  can be assumed =0 when using M-O method for typ. wall designs (Seed and Whitman ,1970; see Kramer p. 479)
- (3) This method does not include a water table.
- (4) This method is only recommended as a rough estimate for tiebacks.
- (5) Check with hand calculations.
- (6) Insert values into yellow areas.
- (7) This method assumes a "Yielding" wall condition
- (8) Paper: "Seismic Design and Behavior of Gravity Retaining Walls" by Robt. V. Whitman(1990)

Parameters	Symbol	Value	Units
Slope Inclination	$\beta$	0.000	radians
Horizontal Acceleration coef/g	$k_h$	0.302	
Vertical Acceleration coef/g	$k_v$	0	
Soil Friction Angle	$\phi$	0.593	radians
Soil/Wall Friction Angle	$\delta$	0.396	radians
Wall Angle (Batter) from Vertical	$\theta$	-0.847	radians
Unit Weight	$\gamma$	115	pcf
Height of Wall	$H$	10.5	feet

#### Conversion from degrees to radians:

Degrees	Radians	Reference	
0	0.0000	Slope	$\beta$
		1.5H:1V	33.7
		1.75H:1V	29.7
34	0.5934	2H:1V	26.6
22.667	0.3956	2.5H:1V	21.8
-48.5	-0.8472	3H:1V	18.4
		3.5H:1V	15.9
		4H:1V	14.0
		5H:1V	11.3
		10H:1V	5.7

To be calculated	Symbol	Value
Coeff. of Active Earth Pressure	$K_a$	calculated
Active earth pressure resultant	$P_a$	calculated
Total Lateral Force	$P_{ae}$	calculated
Dynamic Active Earth Pressure	$K_{ae}$	calculated
Total thrust acts at this height:	$h$	calculated
Critical Failure Surface from Horz.	$\alpha_{ea}$	calculated



#### Active Earth Pressure Calculations

Active Earth Pressure Coefficient	$K_a$	=	0.012
Active thrust static component	$P_a$	=	76 pounds/foot
$\text{ArcTan}(k_h/(1-k_v)) =$	$\psi$	=	0.2933 radians = 16.8 degrees
Dynamic active earth press. coef.	$K_{ae}$	=	0.156
Total Active Thrust	$P_{ae}$	=	991 pounds/foot
Active thrust dynamic component	$\Delta P_{ae}$	=	915 pounds/foot
Total Active Thrust acts at:	$h$	=	6.1 feet
Overturining moment about base	$M_o$	=	5426 ft-lb/ft

Static Equivalent Active Fluid Unit Weight = 1 pcf

Dynamic Equivalent Active Fluid Unit Weight = 18 pcf  
Dynamic Uniform Lateral Surcharge = 87 psf or = 8.3H

Note: The dynamic portion of the equivalent fluid unit weight is typically applied as a rectangular distribution rather than a triangular distribution.

The above calculations correspond to a critical failure surface angle of	$C1E$	0.47	
	$C2E$	0.88	
	$\alpha_{EA}$	= 0.478 radians = 27 degrees above horizontal	

Static conditions produce a critical failure surface angle of	$\alpha_s$	= 1.082 radians = 62 degrees above horizontal
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#### Passive Earth Pressure Calculations

Passive Earth Pressure Coefficient	$K_p$	= 28.80509 (Coulomb)
Passive thrust static component	$P_p$	= 182606 pounds/foot
Dynamic passive earth press. coef	$K_{pe}$	= 9.65
Total Passive Thrust	$P_{pe}$	= 61177 pounds/foot
Passive thrust dynamic component	$\Delta P_{pe}$	= -121429 pounds/foot

Static Equivalent Passive Fluid Unit Weight = 3313 pcf

Dynamic Equivalent Passive Fluid Unit Weight = 1110 pcf

The above calculations correspond to a critical failure surface angle of	$C3E$	4.37	
	$C4E$	-37.33	
	$\alpha_{pe}$	= -0.45 radians = -26 degrees above horizontal	

According to Ref. (8), experimental investigation found good agreement with Wood's theory (applicable to "Non-Yielding" walls), while the measured forces exceeded by a factor of 2 to 3 those predicted by the Mononobe-Okabe (M-O) equation (which is applicable to "Yielding" walls). Therefore, in the case of a "Non-Yielding" wall, Ref. (8) would suggest using an "X" value of 2 to 3 times the above X value obtained for a "Yielding" wall.

Based on this approach, the recommendation in the report might read: " To account for short-term increases in lateral loads on subgrade walls due to seismic forces, apply a pressure (rectangular pressure distribution) equal to  $XH$  for yielding walls and (a value between  $2XH$  and  $3XH$ ) for non-yielding walls. This pressure is in addition to the static lateral pressure."

## Appendix A

### Section 2-5 - ESU 3B - Varying LDCC Batter Angles

#### Seismic Active Lateral Earth Pressure Coefficient, Kae for ESU 3B

##### Mononobe-Okabe Method (M-O)

Pseudo-static analysis of seismic earth pressure on retaining structures

Job Name: I-405 R2B

Job Number: 19047-04

##### NOTES:

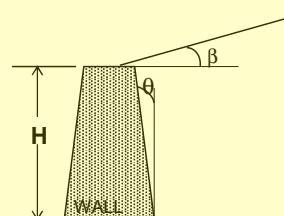
- (1) Refer to Geotechnical Earthquake Engineering by Kramer before using
- (2) Refer to Sections 11.5 & 11.6, 11.8.1.1, and Figure 11.11 a (Kramer)
- Note: 1/3 to 1/2 peak ground surface accelerations are typically used in M-O equation (see Kramer Sect. 11.8.1.1, p. 494)
- $k_v$  can be assumed =0 when using M-O method for typ. wall designs (Seed and Whitman ,1970; see Kramer p. 479)
- (3) This method does not include a water table.
- (4) This method is only recommended as a rough estimate for tiebacks.
- (5) Check with hand calculations.
- (6) Insert values into yellow areas.
- (7) This method assumes a "Yielding" wall condition
- (8) Paper: "Seismic Design and Behavior of Gravity Retaining Walls" by Robt. V. Whitman(1990)

Parameters	Symbol	Value	Units
Slope Inclination	$\beta$	0.000	radians
Horizontal Acceleration coef/g	$k_h$	0.302	
Vertical Acceleration coef/g	$k_v$	0	
Soil Friction Angle	$\phi$	0.593	radians
Soil/Wall Friction Angle	$\delta$	0.396	radians
Wall Angle (Batter) from Vertical	$\theta$	-0.733	radians
Unit Weight	$\gamma$	115	pcf
Height of Wall	$H$	10.5	feet

Conversion from degrees to radians:

Degrees	Radians	Reference	
0	0.0000	Slope	$\beta$
		1.5H:1V	33.7
		1.75H:1V	29.7
34	0.5934	2H:1V	26.6
22.667	0.3956	2.5H:1V	21.8
-42	-0.7330	3H:1V	18.4
		3.5H:1V	15.9
		4H:1V	14.0
		5H:1V	11.3
		10H:1V	5.7

To be calculated	Symbol	Value
Coeff. of Active Earth Pressure	$K_a$	calculated
Active earth pressure resultant	$P_a$	calculated
Total Lateral Force	$P_{ae}$	calculated
Dynamic Active Earth Pressure	$K_{ae}$	calculated
Total thrust acts at this height:	$h$	calculated
Critical Failure Surface from Horz.	$\alpha_{ea}$	calculated



##### Active Earth Pressure Calculations

Active Earth Pressure Coefficient	$K_a$	=	0.034
Active thrust static component	$P_a$	=	216 pounds/foot
$\text{ArcTan}(k_h/(1-k_v)) =$	$\psi$	=	0.2933 radians = 16.8 degrees
Dynamic active earth press. coef.	$K_{ae}$	=	0.200
Total Active Thrust	$P_{ae}$	=	1266 pounds/foot
Active thrust dynamic component	$\Delta P_{ae}$	=	1050 pounds/foot
Total Active Thrust acts at:	$h$	=	5.8 feet
Overturining moment about base	$M_o$	=	6956 ft-lb/ft

Static Equivalent Active Fluid Unit Weight = 4 pcf

Dynamic Equivalent Active Fluid Unit Weight = 23 pcf

Dynamic Uniform Lateral Surcharge = 100 psf or = 9.5H

Note: The dynamic portion of the equivalent fluid unit weight is typically applied as a rectangular distribution rather than a triangular distribution.

The above calculations correspond to a critical failure surface angle of	$C1E$	0.52
	$C2E$	0.96
	$\alpha_{EA}$	= 0.518 radians = 30 degrees above horizontal

Static conditions produce a critical failure surface angle of	$\alpha_s$	= 1.082 radians = 62 degrees above horizontal
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##### Passive Earth Pressure Calculations

Passive Earth Pressure Coefficient	$K_p$	= 92.21577 (Coulomb)
Passive thrust static component	$P_p$	= 584590 pounds/foot
Dynamic passive earth press. coef	$K_{pe}$	= 42.54
Total Passive Thrust	$P_{pe}$	= 269693 pounds/foot
Passive thrust dynamic component	$\Delta P_{pe}$	= -314898 pounds/foot

Static Equivalent Passive Fluid Unit Weight = ##### pcf

Dynamic Equivalent Passive Fluid Unit Weight = 4892 pcf

The above calculations correspond to a critical failure surface angle of	$C3E$	2.78
	$C4E$	-11.36
	$\alpha_{pe}$	= -0.64 radians = -37 degrees above horizontal

According to Ref. (8), experimental investigation found good agreement with Wood's theory (applicable to "Non-Yielding" walls), while the measured forces exceeded by a factor of 2 to 3 those predicted by the Mononobe-Okabe (M-O) equation (which is applicable to "Yielding" walls). Therefore, in the case of a "Non-Yielding" wall, Ref. (8) would suggest using an "X" value of 2 to 3 times the above X value obtained for a "Yielding" wall.

Based on this approach, the recommendation in the report might read: " To account for short-term increases in lateral loads on subgrade walls due to seismic forces, apply a pressure (rectangular pressure distribution) equal to  $XH$  for yielding walls and (a value between  $2XH$  and  $3XH$ ) for non-yielding walls. This pressure is in addition to the static lateral pressure."

## Appendix A

### Section 2-5 - ESU 3B - Varying LDCC Batter Angles

#### Seismic Active Lateral Earth Pressure Coefficient, Kae for ESU 3B

##### Mononobe-Okabe Method (M-O)

Pseudo-static analysis of seismic earth pressure on retaining structures

Job Name: I-405 R2B

Job Number: 19047-04

##### NOTES:

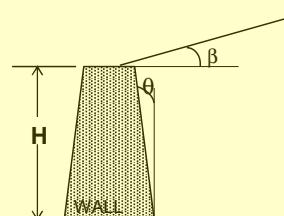
- (1) Refer to Geotechnical Earthquake Engineering by Kramer before using
- (2) Refer to Sections 11.5 & 11.6, 11.8.1.1, and Figure 11.11 a (Kramer)
- Note: 1/3 to 1/2 peak ground surface accelerations are typically used in M-O equation (see Kramer Sect. 11.8.1.1, p. 494)
- $k_v$  can be assumed =0 when using M-O method for typ. wall designs (Seed and Whitman ,1970; see Kramer p. 479)
- (3) This method does not include a water table.
- (4) This method is only recommended as a rough estimate for tiebacks.
- (5) Check with hand calculations.
- (6) Insert values into yellow areas.
- (7) This method assumes a "Yielding" wall condition
- (8) Paper: "Seismic Design and Behavior of Gravity Retaining Walls" by Robt. V. Whitman(1990)

Parameters	Symbol	Value	Units
Slope Inclination	$\beta$	0.000	radians
Horizontal Acceleration coef/g	$k_h$	0.302	
Vertical Acceleration coef/g	$k_v$	0	
Soil Friction Angle	$\phi$	0.593	radians
Soil/Wall Friction Angle	$\delta$	0.396	radians
Wall Angle (Batter) from Vertical	$\theta$	-0.471	radians
Unit Weight	$\gamma$	115	pcf
Height of Wall	$H$	10.5	feet

##### Conversion from degrees to radians:

Degrees	Radians	Reference	
0	0.0000	Slope	$\beta$
		1.5H:1V	33.7
		1.75H:1V	29.7
34	0.5934	2H:1V	26.6
22.667	0.3956	2.5H:1V	21.8
-27	-0.4712	3H:1V	18.4
		3.5H:1V	15.9
		4H:1V	14.0
		5H:1V	11.3
		10H:1V	5.7

To be calculated	Symbol	Value
Coeff. of Active Earth Pressure	$K_a$	calculated
Active earth pressure resultant	$P_a$	calculated
Total Lateral Force	$P_{ae}$	calculated
Dynamic Active Earth Pressure	$K_{ae}$	calculated
Total thrust acts at this height:	$h$	calculated
Critical Failure Surface from Horz.	$\alpha_{ea}$	calculated



##### Active Earth Pressure Calculations

Active Earth Pressure Coefficient	$K_a$	=	0.100
Active thrust static component	$P_a$	=	632 pounds/foot
$\text{ArcTan}(kh/(1-kv)) =$	$\psi$	=	0.2933 radians = 16.8 degrees
Dynamic active earth press. coef.	$K_{ae}$	=	0.295
Total Active Thrust	$P_{ae}$	=	1869 pounds/foot
Active thrust dynamic component	$\Delta P_{ae}$	=	1237 pounds/foot
Total Active Thrust acts at:	$h$	=	5.4 feet
Overturining moment about base	$M_o$	=	9975 ft-lb/ft

Static Equivalent Active Fluid Unit Weight = 11 pcf

Dynamic Equivalent Active Fluid Unit Weight = 34 pcf  
Dynamic Uniform Lateral Surcharge = 118 psf or = 11.2H

Note: The dynamic portion of the equivalent fluid unit weight is typically applied as a rectangular distribution rather than a triangular distribution.

The above calculations correspond to a critical failure surface angle of	$C1E$	0.71
	$C2E$	1.30
	$\alpha_{EA}$	= 0.602 radians = 34 degrees above horizontal

Static conditions produce a critical failure surface angle of	$\alpha_s$	= 1.082 radians = 62 degrees above horizontal
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##### Passive Earth Pressure Calculations

Passive Earth Pressure Coefficient	$K_p$	= 192.0232 (Coulomb)
Passive thrust static component	$P_p$	= 1217307 pounds/foot
Dynamic passive earth press. coef	$K_{pe}$	= 115.18
Total Passive Thrust	$P_{pe}$	= 730173 pounds/foot
Passive thrust dynamic component	$\Delta P_{pe}$	= -487134 pounds/foot

Static Equivalent Passive Fluid Unit Weight = ##### pcf

Dynamic Equivalent Passive Fluid Unit Weight = ##### pcf

The above calculations correspond to a critical failure surface angle of	$C3E$	4.56
	$C4E$	-11.58
	$\alpha_{pe}$	= -0.76 radians = -44 degrees above horizontal

According to Ref. (8), experimental investigation found good agreement with Wood's theory (applicable to "Non-Yielding" walls), while the measured forces exceeded by a factor of 2 to 3 those predicted by the Mononobe-Okabe (M-O) equation (which is applicable to "Yielding" walls). Therefore, in the case of a "Non-Yielding" wall, Ref. (8) would suggest using an "X" value of 2 to 3 times the above X value obtained for a "Yielding" wall.

Based on this approach, the recommendation in the report might read: " To account for short-term increases in lateral loads on subgrade walls due to seismic forces, apply a pressure (rectangular pressure distribution) equal to  $XH$  for yielding walls and (a value between  $2XH$  and  $3XH$ ) for non-yielding walls. This pressure is in addition to the static lateral pressure."

## Appendix A

### Section 2-5 - ESU 3B - Varying LDCC Batter Angles

#### Seismic Active Lateral Earth Pressure Coefficient, Kae for ESU 3B

##### Mononobe-Okabe Method (M-O)

Pseudo-static analysis of seismic earth pressure on retaining structures

Job Name: I-405 R2B

Job Number: 19047-04

##### NOTES:

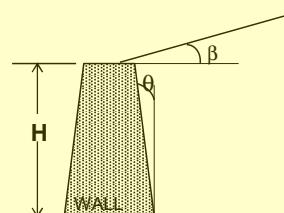
- (1) Refer to Geotechnical Earthquake Engineering by Kramer before using
- (2) Refer to Sections 11.5 & 11.6, 11.8.1.1, and Figure 11.11 a (Kramer)
- Note: 1/3 to 1/2 peak ground surface accelerations are typically used in M-O equation (see Kramer Sect. 11.8.1.1, p. 494)
- $k_v$  can be assumed =0 when using M-O method for typ. wall designs (Seed and Whitman ,1970; see Kramer p. 479)
- (3) This method does not include a water table.
- (4) This method is only recommended as a rough estimate for tiebacks.
- (5) Check with hand calculations.
- (6) Insert values into yellow areas.
- (7) This method assumes a "Yielding" wall condition
- (8) Paper: "Seismic Design and Behavior of Gravity Retaining Walls" by Robt. V. Whitman(1990)

Parameters	Symbol	Value	Units
Slope Inclination	$\beta$	0.000	radians
Horizontal Acceleration coef/g	$k_h$	0.302	
Vertical Acceleration coef/g	$k_v$	0	
Soil Friction Angle	$\phi$	0.593	radians
Soil/Wall Friction Angle	$\delta$	0.396	radians
Wall Angle (Batter) from Vertical	$\theta$	-0.227	radians
Unit Weight	$\gamma$	115	pcf
Height of Wall	$H$	10.5	feet

Conversion from degrees to radians:

Degrees	Radians	Reference	
0	0.0000	Slope	$\beta$
		1.5H:1V	33.7
		1.75H:1V	29.7
34	0.5934	2H:1V	26.6
22.667	0.3956	2.5H:1V	21.8
-13	-0.2269	3H:1V	18.4
		3.5H:1V	15.9
		4H:1V	14.0
		5H:1V	11.3
		10H:1V	5.7

To be calculated	Symbol	Value
Coeff. of Active Earth Pressure	$K_a$	calculated
Active earth pressure resultant	$P_a$	calculated
Total Lateral Force	$P_{ae}$	calculated
Dynamic Active Earth Pressure	$K_{ae}$	calculated
Total thrust acts at this height:	$h$	calculated
Critical Failure Surface from Horz.	$\alpha_{ea}$	calculated



##### Active Earth Pressure Calculations

Active Earth Pressure Coefficient	$K_a$	=	0.172
Active thrust static component	$P_a$	=	1093 pounds/foot
$\text{ArcTan}(k_h/(1-k_v)) =$	$\psi$	=	0.2933 radians = 16.8 degrees
Dynamic active earth press. coef.	$K_{ae}$	=	0.391
Total Active Thrust	$P_{ae}$	=	2480 pounds/foot
Active thrust dynamic component	$\Delta P_{ae}$	=	1386 pounds/foot
Total Active Thrust acts at:	$h$	=	5.1 feet
Overturining moment about base	$M_o$	=	12382 ft-lb/ft

Static Equivalent Active Fluid Unit Weight = 20 pcf

Dynamic Equivalent Active Fluid Unit Weight = 45 pcf  
Dynamic Uniform Lateral Surcharge = 132 psf or = 12.6H

Note: The dynamic portion of the equivalent fluid unit weight is typically applied as a rectangular distribution rather than a triangular distribution.

The above calculations correspond to a critical failure surface angle of	$C1E$	1.08
	$C2E$	2.01
	$\alpha_{EA}$	= 0.666 radians = 38 degrees above horizontal

Static conditions produce a critical failure surface angle of	$\alpha_s$	= 1.082 radians = 62 degrees above horizontal
---	------------	---

##### Passive Earth Pressure Calculations

Passive Earth Pressure Coefficient	$K_p$	= 21.03791 (Coulomb)
Passive thrust static component	$P_p$	= 133367 pounds/foot
Dynamic passive earth press. coef	$K_{pe}$	= 14.26
Total Passive Thrust	$P_{pe}$	= 90417 pounds/foot
Passive thrust dynamic component	$\Delta P_{pe}$	= -42950 pounds/foot

Static Equivalent Passive Fluid Unit Weight = 2419 pcf

Dynamic Equivalent Passive Fluid Unit Weight = 1640 pcf

The above calculations correspond to a critical failure surface angle of	$C3E$	8.99
	$C4E$	19.15
	$\alpha_{pe}$	= 0.19 radians = 11 degrees above horizontal

According to Ref. (8), experimental investigation found good agreement with Wood's theory (applicable to "Non-Yielding" walls), while the measured forces exceeded by a factor of 2 to 3 those predicted by the Mononobe-Okabe (M-O) equation (which is applicable to "Yielding" walls). Therefore, in the case of a "Non-Yielding" wall, Ref. (8) would suggest using an "X" value of 2 to 3 times the above X value obtained for a "Yielding" wall.

Based on this approach, the recommendation in the report might read: " To account for short-term increases in lateral loads on subgrade walls due to seismic forces, apply a pressure (rectangular pressure distribution) equal to  $XH$  for yielding walls and (a value between  $2XH$  and  $3XH$ ) for non-yielding walls. This pressure is in addition to the static lateral pressure."

## Appendix A

### Section 2-5 - ESU 3B - Varying LDCC Batter Angles

#### Seismic Active Lateral Earth Pressure Coefficient, Kae for ESU 3B

##### Mononobe-Okabe Method (M-O)

Pseudo-static analysis of seismic earth pressure on retaining structures

Job Name: I-405 R2B

Job Number: 19047-04

##### NOTES:

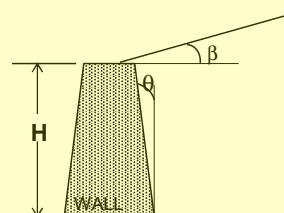
- (1) Refer to Geotechnical Earthquake Engineering by Kramer before using
- (2) Refer to Sections 11.5 & 11.6, 11.8.1.1, and Figure 11.11 a (Kramer)
- Note: 1/3 to 1/2 peak ground surface accelerations are typically used in M-O equation (see Kramer Sect. 11.8.1.1, p. 494)
- $k_v$  can be assumed =0 when using M-O method for typ. wall designs (Seed and Whitman ,1970; see Kramer p. 479)
- (3) This method does not include a water table.
- (4) This method is only recommended as a rough estimate for tiebacks.
- (5) Check with hand calculations.
- (6) Insert values into yellow areas.
- (7) This method assumes a "Yielding" wall condition
- (8) Paper: "Seismic Design and Behavior of Gravity Retaining Walls" by Robt. V. Whitman(1990)

Parameters	Symbol	Value	Units
Slope Inclination	$\beta$	0.000	radians
Horizontal Acceleration coef/g	$k_h$	0.302	
Vertical Acceleration coef/g	$k_v$	0	
Soil Friction Angle	$\phi$	0.593	radians
Soil/Wall Friction Angle	$\delta$	0.396	radians
Wall Angle (Batter) from Vertical	$\theta$	0.000	radians
Unit Weight	$\gamma$	115	pcf
Height of Wall	$H$	10.5	feet

Conversion from degrees to radians:

Degrees	Radians	Reference	
0	0.0000	Slope	$\beta$
		1.5H:1V	33.7
		1.75H:1V	29.7
34	0.5934	2H:1V	26.6
22.667	0.3956	2.5H:1V	21.8
0	0.0000	3H:1V	18.4
		3.5H:1V	15.9
		4H:1V	14.0
		5H:1V	11.3
		10H:1V	5.7

To be calculated	Symbol	Value
Coeff. of Active Earth Pressure	$K_a$	calculated
Active earth pressure resultant	$P_a$	calculated
Total Lateral Force	$P_{ae}$	calculated
Dynamic Active Earth Pressure	$K_{ae}$	calculated
Total thrust acts at this height:	$h$	calculated
Critical Failure Surface from Horz.	$\alpha_{ea}$	calculated



##### Active Earth Pressure Calculations

Active Earth Pressure Coefficient	$K_a$	=	0.254
Active thrust static component	$P_a$	=	1612 pounds/foot
$\text{ArcTan}(k_h/(1-k_v)) =$	$\psi$	=	0.2933 radians = 16.8 degrees
Dynamic active earth press. coef.	$K_{ae}$	=	0.504
Total Active Thrust	$P_{ae}$	=	3194 pounds/foot
Active thrust dynamic component	$\Delta P_{ae}$	=	1582 pounds/foot
Total Active Thrust acts at:	$h$	=	4.9 feet
Overturining moment about base	$M_o$	=	14402 ft-lb/ft

Static Equivalent Active Fluid Unit Weight = 29 pcf

Dynamic Equivalent Active Fluid Unit Weight = 58 pcf

Dynamic Uniform Lateral Surcharge = 151 psf or = 14.3H

Note: The dynamic portion of the equivalent fluid unit weight is typically applied as a rectangular distribution rather than a triangular distribution.

The above calculations correspond to a critical failure surface angle of	$C1E$	2.00
	$C2E$	3.92
	$\alpha_{EA}$	= 0.708 radians = 41 degrees above horizontal

Static conditions produce a critical failure surface angle of	$\alpha_s$	= 1.082 radians = 62 degrees above horizontal
---	------------	---

##### Passive Earth Pressure Calculations

Passive Earth Pressure Coefficient	$K_p$	= 8.951997 (Coulomb)
Passive thrust static component	$P_p$	= 56750 pounds/foot
Dynamic passive earth press. coef	$K_{pe}$	= 6.55
Total Passive Thrust	$P_{pe}$	= 41498 pounds/foot
Passive thrust dynamic component	$\Delta P_{pe}$	= -15252 pounds/foot

Static Equivalent Passive Fluid Unit Weight = 1029 pcf

Dynamic Equivalent Passive Fluid Unit Weight = 753 pcf

The above calculations correspond to a critical failure surface angle of	$C3E$	2.00
	$C4E$	3.92
	$\alpha_{pe}$	= 0.39 radians = 22 degrees above horizontal

According to Ref. (8), experimental investigation found good agreement with Wood's theory (applicable to "Non-Yielding" walls), while the measured forces exceeded by a factor of 2 to 3 those predicted by the Mononobe-Okabe (M-O) equation (which is applicable to "Yielding" walls). Therefore, in the case of a "Non-Yielding" wall, Ref. (8) would suggest using an "X" value of 2 to 3 times the above X value obtained for a "Yielding" wall.

Based on this approach, the recommendation in the report might read: " To account for short-term increases in lateral loads on subgrade walls due to seismic forces, apply a pressure (rectangular pressure distribution) equal to  $XH$  for yielding walls and (a value between  $2XH$  and  $3XH$ ) for non-yielding walls. This pressure is in addition to the static lateral pressure."

## Appendix A

### Section 3 - LDCC Minimum Width for Varying LDCC Batter

Minimum width of LDCC required for sliding resistance to overcome seismic active earth pressures behind the LDCC mass

Input Cell  
Calculation Cell

#### LDCC Parameters

LDCC Unit Weight, pcf	35
LDCC Height, ft	10.5

#### Sliding Resistance of LDCC for Different Bearing Layers

Bearing Soil	Friction Angle (deg)	Cohesion (psf)	Sliding Resistance (psf) <sup>a</sup>
ESU 3B	34	0	247.88
ESU 4D	35	700	957.33

Notes:

a. Lower sliding resistance between ESU 3B and ESU 4D bearing layer used to calculate minimum required width of LDCC.

#### Minimum LDCC Width for Varying LDCC Batter Angles, Flat Backslope

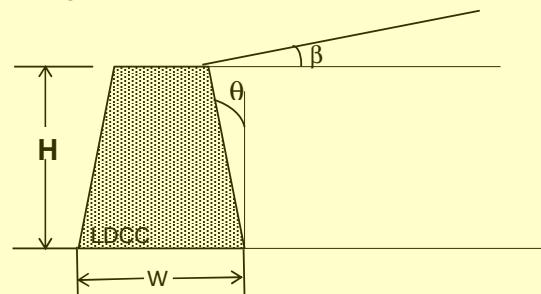
LDCC Width (ft)	LDCC Sliding Resistance Bearing on ESU 3B (lb/ft)	LDCC Backslope from Vertical, $\theta$ (deg)*	LDCC Backslope from Horizontal (deg)	LDCC Backslope (H:V)
4	992	-48	42	1.11
5	1239	-42	48	0.90
7.5	1859	-27	63	0.51
10	2479	-13	77	0.23
13	3222	0	90	0.00

Notes:

a. Backslopes correspond to the seismic active earth pressure of ESU 3B equal to the LDCC sliding resistance for the selected width.

b. See seismic active earth pressure calculation for each backslope angle in Mononobe-Okabe LEP calculation spreadsheets.

c. Sliding calculated per AASHTO LRFD Section 10.6.3.4.



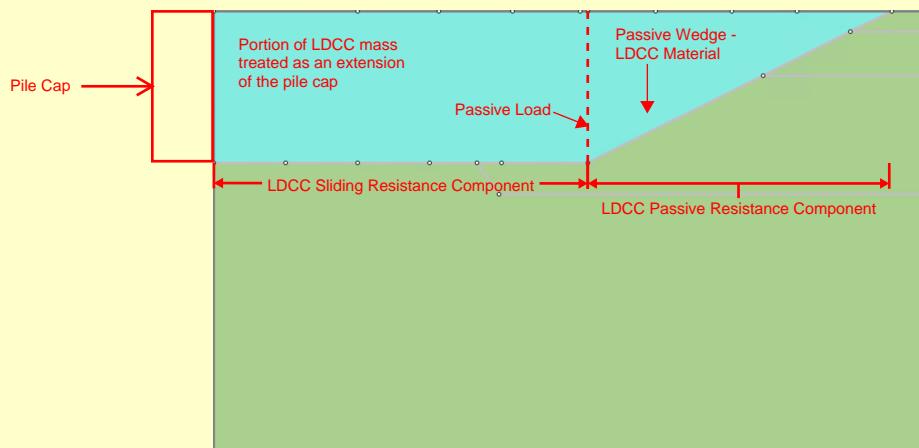
## Static and Seismic Passive Pressure Calculation Documentation

The following documents the methods used to estimate the static and seismic passive pressure coefficients for the soil present behind the LDCC.

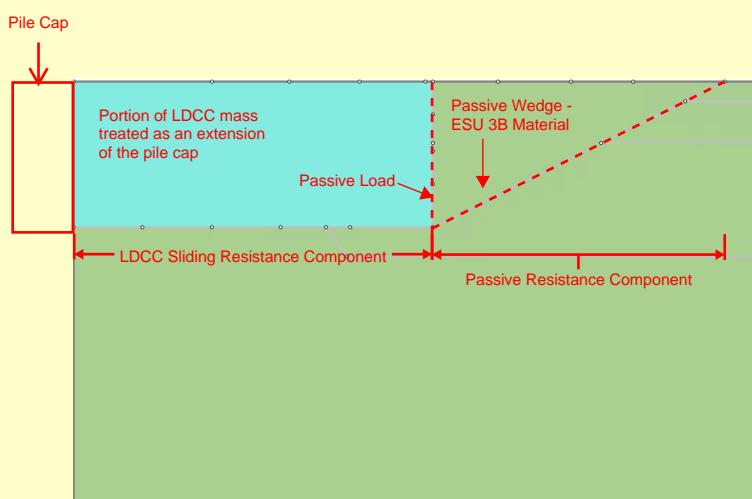
To evaluate the passive resistance separate from the sliding resistance of the LDCC mass, we treated the rectangular prism of the LDCC as an extension of the pile cap. Therefore the passive load is applied to the vertical face at the edge of the LDCC width. See figure below.

We understand that when the LDCC is battered, it will be cast against the existing ESU 3B soil. Because ESU 3B is a weaker material than the cured LDCC material, the ESU 3B soil will fail in passive before the LDCC, and therefore is the controlling passive earth pressure coefficient. Figures A-1 through A-3 show the failure surface from GLE methods going through the ESU 3B material when a passive pressure is applied to the face of the battered LDCC. Because the overburden material within the failure wedge is the LDCC material, as shown in Slide Figures A-1 through A-3, the passive pressure is calculated using the unit weight of the LDCC. See figure below.

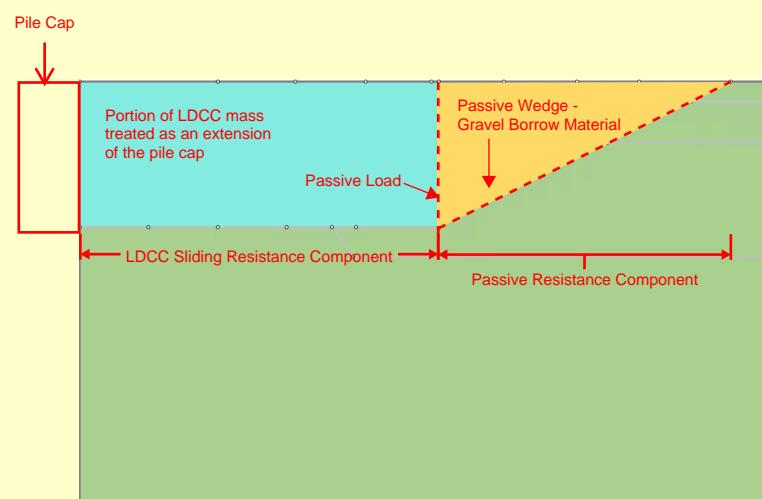
In the case where the LDCC is cast with a vertical face, the passive load is applied to the material behind the LDCC, and the passive wedge is formed in that material. Therefore, the passive pressure is calculated using the passive earth pressure coefficient and unit weight of the material behind the LDCC.



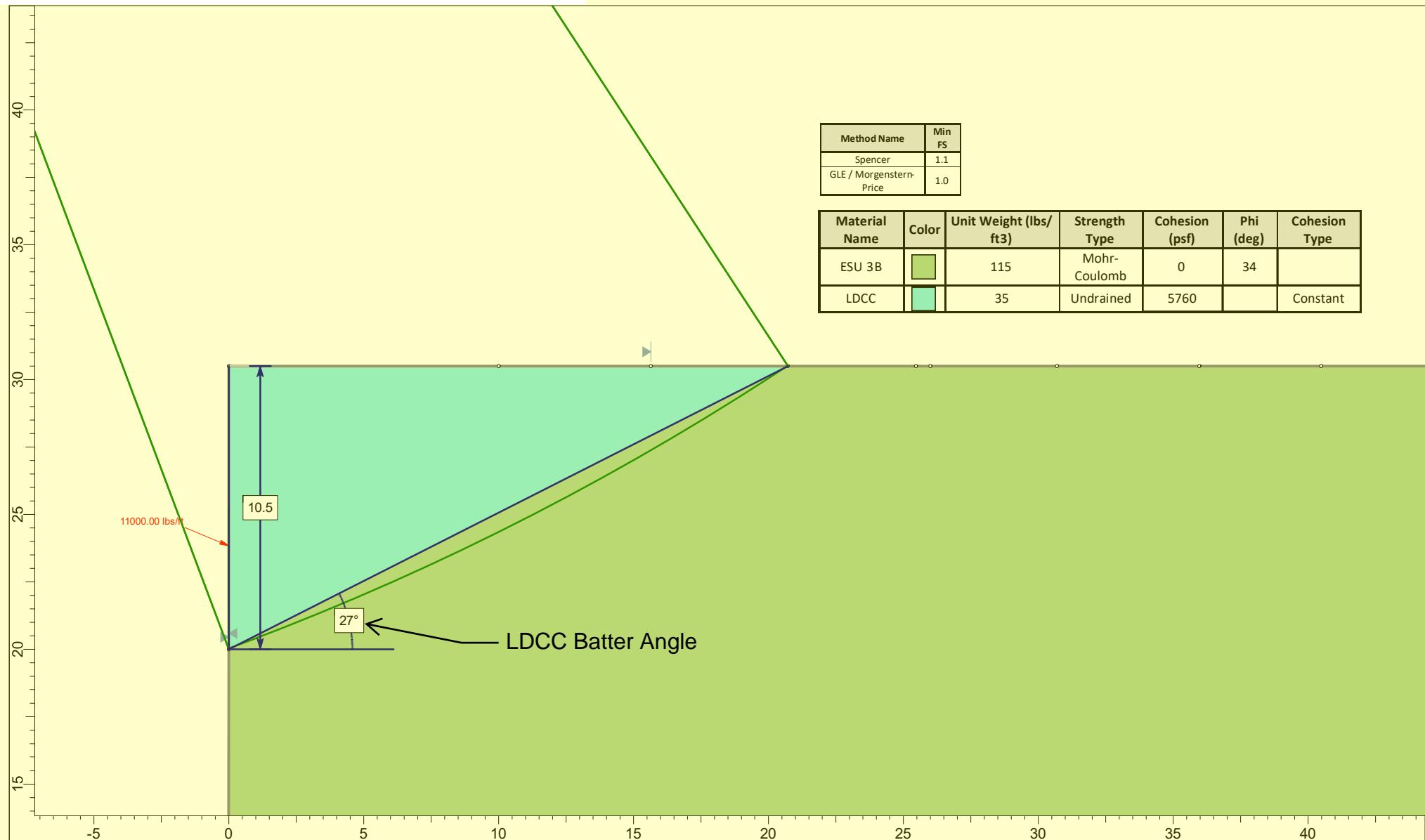
Battered LDCC - passive pressure calculated using ESU 3B passive earth pressure coefficient and LDCC unit weight.



Vertical LDCC, vertical excavation shored and LDCC cast against ESU 3B - passive pressure calculated using ESU 3B passive earth pressure coefficient and unit weight.



Vertical LDCC, sloped excavation backfilled with gravel borrow and LDCC cast against backfill material - passive pressure calculated using gravel borrow passive earth pressure coefficient and unit weight.



## Notes:

1. Per AASHTO LRFD Section 3.11.5.4 and the applied lateral load on the soil (11,000 lb/ft), the back-calculated passive lateral earth pressure coefficient, Kp, of the non-cohesive soil from this SLIDE analysis is approximately 5.701, where  $Kp = 11,000 \text{ lb/ft} / (\gamma_{\text{soil}} * H^2 * 0.5)$ .

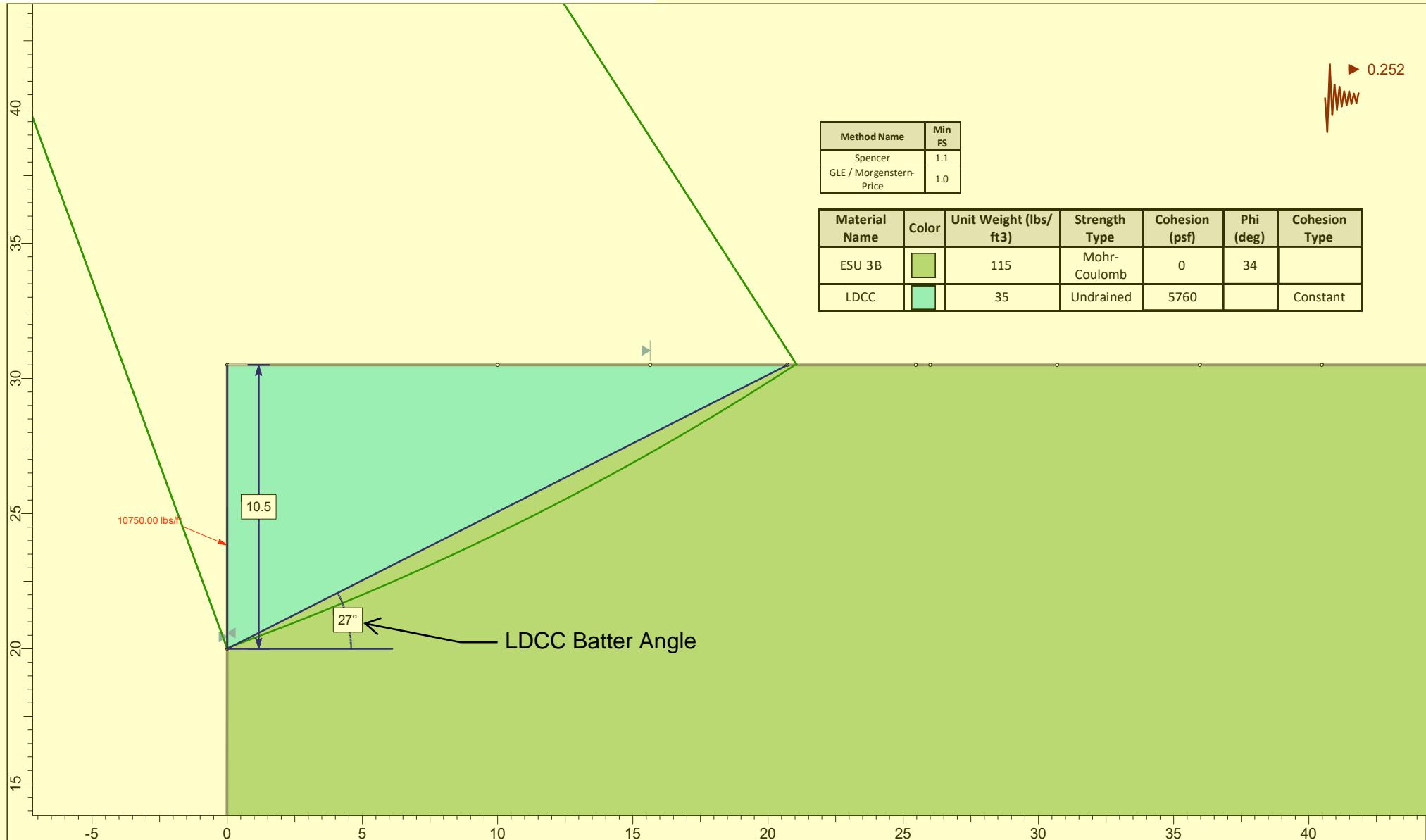
I-405 Renton to Bellevue Express Toll Lanes  
Bellevue, Washington

Bridge 28 East LDCC Fill - ESU 3B Retained Soil -  
Kp - 2H:1V LDCC Batter Angle

19434-04

Scale 1:60

8/21

**Notes:**

1. Per AASHTO LRFD Section 3.11.5.4 and the applied lateral load on the soil (10,750 lb/ft), the back-calculated seismic passive lateral earth pressure coefficient,  $K_{pe}$ , of the non-cohesive soil from this SLIDE analysis is approximately 5.572, where  $K_p = 11,000 \text{ lb/ft} / (\gamma_{\text{soil}} * H^2 * 0.5)$ .
2. The horizontal acceleration coefficient,  $K_h$ , is taken as  $K_h = 0.5 * K_{h0}$ .

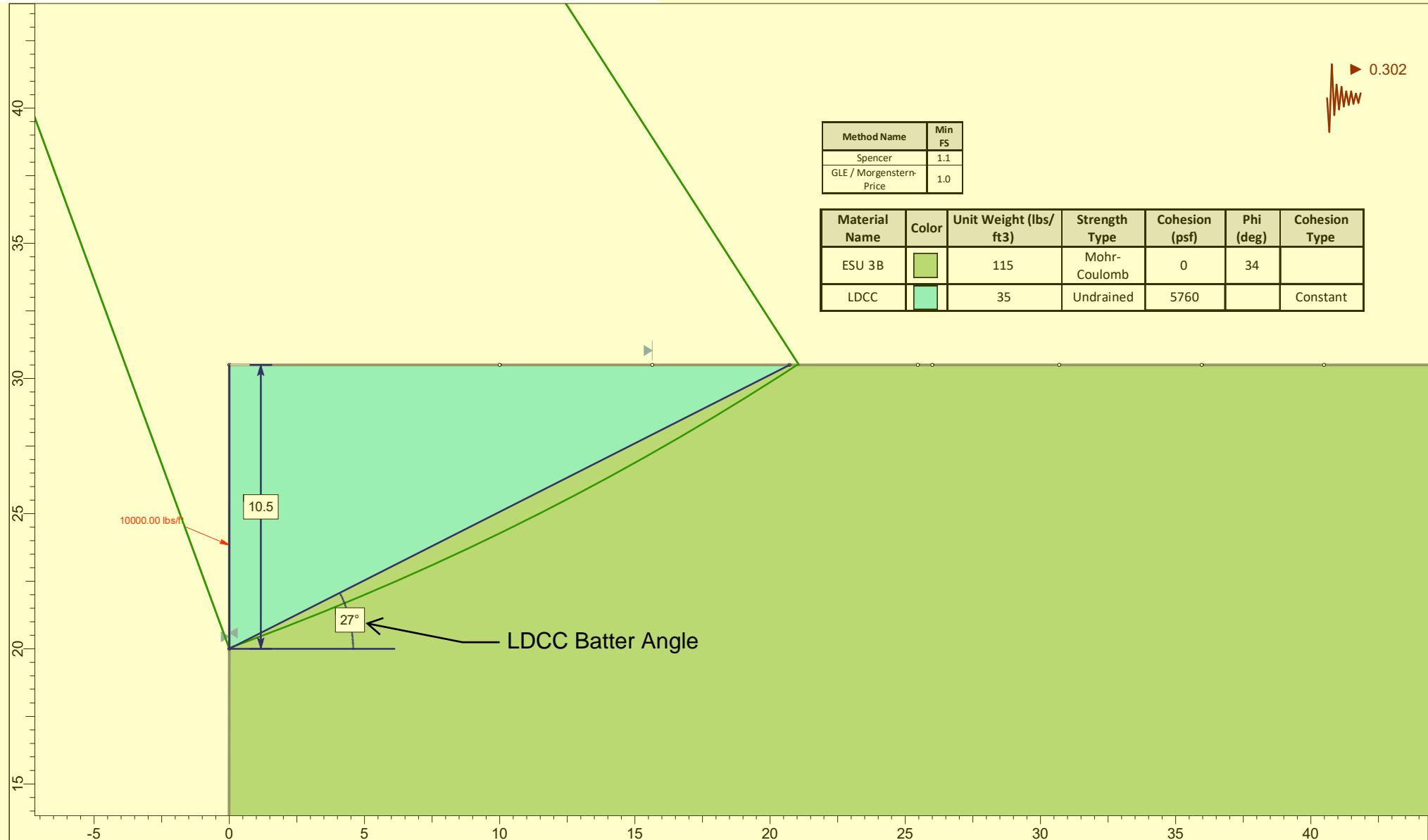
I-405 Renton to Bellevue Express Toll Lanes  
Bellevue, Washington

**Bridge 28 East LDCC Fill - ESU 3B Retained Soil -  
 $K_{pe} - 0.5 * K_h - 2H:1V$  LDCC Batter Angle**

19434-04

Scale 1:60

8/21

**Notes:**

1. Per AASHTO LRFD Section 3.11.5.4 and the applied lateral load on the soil (10,000 lb/ft), the back-calculated seismic passive lateral earth pressure coefficient, Kpe, of the non-cohesive soil from this SLIDE analysis is approximately 5.183, where  $K_p = 11,000 \text{ lb/ft} / (\gamma_{\text{soil}} * H^2 * 0.5)$ .
2. The horizontal acceleration coefficient,  $K_h$ , is taken as  $K_h = 0.6 * K_{h0}$ .

I-405 Renton to Bellevue Express Toll Lanes  
Bellevue, Washington

**Bridge 28 East LDCC Fill - ESU 3B Retained Soil -  
Kpe - 0.6\*Kh - 2H:1V LDCC Batter Angle**

19434-04

Scale 1:60

8/21



ESU 3B - LDCC with 2H:1V Batter - See Figures A-1 to A-3



LDCC\_21.08.18

SLIDE - An Interactive Slope Stability Program

Date Created: 7/1/2021, 3:44:03 PM

Software Version: 9.018

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# Slide Analysis Information

## LDCC\_21.08.18

### Project Summary

File Name: LDCC\_21.08.18.slmd  
Slide Modeler Version: 9.018  
Project Title: SLIDE - An Interactive Slope Stability Program  
Date Created: 7/1/2021, 3:44:03 PM

### Currently Open Scenarios

Group Name	Scenario Name	Global Minimum	Compute Time
LDCC	Master Scenario	Spencer: 11.540800 Gle/morgenstern-price: 12.221000	00h:00m:40.128s
	Kp - 2H:1V LDCC Batter Angle	Spencer: 1.095250 Gle/morgenstern-price: 1.019930	00h:00m:01.616s
	Kpe - 0.6*Kh - 2H:1V LDCC Batter Angle	Spencer: 1.085700 Gle/morgenstern-price: 0.997623	00h:00m:01.265s
	Kpe - 0.5*Kh - 2H:1V LDCC Batter Angle	Spencer: 1.051050 Gle/morgenstern-price: 0.966542	00h:00m:01.300s

## General Settings

Units of Measurement:	Imperial Units			
Time Units:	days			
Permeability Units:	feet/second			
Data Output:	Standard			
Master Scenario	Kp - 2H:1V LDCC Batter Angle	Kpe - 0.6*Kh - 2H:1V LDCC Batter Angle	Kpe - 0.5*Kh - 2H:1V LDCC Batter Angle	
Failure Direction:	Right to Left	Left to Right	Left to Right	Left to Right

# Analysis Options

## All Open Scenarios

Slices Type:	Vertical
<b>Analysis Methods Used</b>	
Number of slices:	GLE/Morgenstern-Price with interslice force function (Half Sine)
Tolerance:	Spencer
Maximum number of iterations:	50
Check malpha < 0.2:	0.005
Create Interslice boundaries at intersections with water tables and piezos:	75
Initial trial value of FS:	Yes
Steffensen Iteration:	Yes

# Groundwater Analysis

---

## All Open Scenarios

Groundwater Method:	Water Surfaces
Pore Fluid Unit Weight [lbs/ft3]:	62.4
Use negative pore pressure cutoff:	Yes
Maximum negative pore pressure [psf]:	0
Advanced Groundwater Method:	None

# Random Numbers

---

## All Open Scenarios

Pseudo-random Seed:  
Random Number Generation Method:

10116  
Park and Miller v.3

## Surface Options

### ◆ LDCC - Kp - 2H:1V LDCC Batter Angle

Surface Type:	Circular
Search Method:	Auto Refine Search
Divisions along slope:	20
Circles per division:	10
Number of iterations:	10
Divisions to use in next iteration:	50%
Composite Surfaces:	Disabled
Minimum Elevation:	Not Defined
Minimum Depth:	Not Defined
Minimum Area:	Not Defined
Minimum Weight:	Not Defined

### All other Scenarios

Search Method:	Cuckoo Search
Initial # of Surface Vertices:	8
Maximum Iterations:	500
Number of Nests:	50
Minimum Elevation:	Not Defined
Minimum Depth:	Not Defined
Minimum Area:	Not Defined
Minimum Weight:	Not Defined
Convex Surfaces Only:	Enabled

# Seismic Loading

---

## ◆ **LDCC - Master Scenario**

Advanced seismic analysis:	No
Staged pseudostatic analysis:	No

## ◆ **LDCC - Kp - 2H:1V LDCC Batter Angle**

Advanced seismic analysis:	No
Staged pseudostatic analysis:	No

## ◆ **LDCC - Kpe - 0.6\*Kh - 2H:1V LDCC Batter Angle**

Advanced seismic analysis:	No
Staged pseudostatic analysis:	No
Seismic Load Coefficient (Horizontal):	0.302

## ◆ **LDCC - Kpe - 0.5\*Kh - 2H:1V LDCC Batter Angle**

Advanced seismic analysis:	No
Staged pseudostatic analysis:	No
Seismic Load Coefficient (Horizontal):	0.252

## Loading

---

### ◆ **LDCC - Kp - 2H:1V LDCC Batter Angle**

Angle from horizontal [deg]: 337.4  
Magnitude: 11000

### ◆ **LDCC - Kpe - 0.6\*Kh - 2H:1V LDCC Batter Angle**

Angle from horizontal [deg]: 337.4  
Magnitude: 10000

### ◆ **LDCC - Kpe - 0.5\*Kh - 2H:1V LDCC Batter Angle**

Angle from horizontal [deg]: 337.4  
Magnitude: 10750

# Materials

## ESU 3B

Color	
Strength Type	Mohr-Coulomb
Unit Weight [lbs/ft3]	115
Cohesion [psf]	0
Friction Angle [deg]	34
Water Surface	Assigned per scenario
Ru Value	0

## ESU 3C

Color	
Strength Type	Mohr-Coulomb
Unit Weight [lbs/ft3]	135
Cohesion [psf]	0
Friction Angle [deg]	38
Water Surface	Assigned per scenario
Ru Value	0

## ESU 3D

Color	
Strength Type	Mohr-Coulomb
Unit Weight [lbs/ft3]	140
Cohesion [psf]	0
Friction Angle [deg]	42
Water Surface	Assigned per scenario
Ru Value	0

## ESU 4D

Color	
Strength Type	Mohr-Coulomb
Unit Weight [lbs/ft3]	130
Cohesion [psf]	700
Friction Angle [deg]	35
Water Surface	Assigned per scenario
Ru Value	0

## LDCC

Color	
Strength Type	Undrained
Unit Weight [lbs/ft3]	35
Cohesion [psf]	5760
Cohesion Type	Constant
Water Surface	Assigned per scenario
Ru Value	0

## Materials In Use

Material	LDCC	Kp - 2H:1V LDCC Batter Angle	Kpe - 0.6*Kh - 2H:1V LDCC Batter Angle	Kpe - 0.5*Kh - 2H:1V LDCC Batter Angle
ESU 3B		✓	✓	✓
ESU 3C		✗	✗	✗
ESU 3D		✗	✗	✗
ESU 4D		✗	✗	✗
LDCC		✓	✓	✓

# Global Minimums

## ◆ LDCC - Master Scenario

### Method: spencer

FS	<b>11.540800</b>
Axis Location:	37.083, 55.198
Left Slip Surface Endpoint:	24.734, 30.500
Right Slip Surface Endpoint:	49.431, 30.500
Resisting Moment:	2.2271e+06 lb-ft
Driving Moment:	192977 lb-ft
Resisting Horizontal Force:	57356.5 lb
Driving Horizontal Force:	4969.89 lb
Total Slice Area:	212.455 ft <sup>2</sup>
Surface Horizontal Width:	24.6978 ft
Surface Average Height:	8.6022 ft

### Method: gle/morgenstern-price

FS	<b>12.221000</b>
Axis Location:	30.648, 69.205
Left Slip Surface Endpoint:	11.295, 30.500
Right Slip Surface Endpoint:	50.000, 30.500
Resisting Moment:	6.46033e+06 lb-ft
Driving Moment:	528624 lb-ft
Resisting Horizontal Force:	103200 lb
Driving Horizontal Force:	8444.44 lb
Total Slice Area:	537.497 ft <sup>2</sup>
Surface Horizontal Width:	38.7048 ft
Surface Average Height:	13.8871 ft

## ◆ LDCC - Kp - 2H:1V LDCC Batter Angle

### Method: spencer

FS	<b>1.095250</b>
Center:	-36.327, 120.521
Radius:	106.881
Left Slip Surface Endpoint:	-0.000, 20.003
Right Slip Surface Endpoint:	21.290, 30.500
Left Slope Intercept:	-0.000 25.250
Right Slope Intercept:	21.290 30.500
Resisting Moment:	646031 lb-ft
Driving Moment:	589847 lb-ft
Resisting Horizontal Force:	5492.04 lb
Driving Horizontal Force:	5014.41 lb
Total Slice Area:	122.199 ft <sup>2</sup>
Surface Horizontal Width:	21.2898 ft
Surface Average Height:	5.73976 ft

### Method: gle/morgenstern-price

FS	1.019930
Center:	-37.072, 118.905
Radius:	105.621
Left Slip Surface Endpoint:	-0.000, 20.003
Right Slip Surface Endpoint:	20.725, 30.500
Left Slope Intercept:	-0.000 25.250
Right Slope Intercept:	20.725 30.500
Resisting Moment:	598705 lb-ft
Driving Moment:	587005 lb-ft
Resisting Horizontal Force:	5075.96 lb
Driving Horizontal Force:	4976.77 lb
Total Slice Area:	118.694 ft <sup>2</sup>
Surface Horizontal Width:	20.7247 ft
Surface Average Height:	5.7272 ft

#### ◆ LDCC - Kpe - 0.6\*Kh - 2H:1V LDCC Batter Angle

**Method: spencer**

FS	1.085700
Center:	-36.576, 119.856
Radius:	106.334
Left Slip Surface Endpoint:	-0.000, 20.011
Right Slip Surface Endpoint:	21.064, 30.500
Left Slope Intercept:	-0.000 25.250
Right Slope Intercept:	21.064 30.500
Resisting Moment:	717346 lb-ft
Driving Moment:	660721 lb-ft
Resisting Horizontal Force:	6128.15 lb
Driving Horizontal Force:	5644.42 lb
Total Slice Area:	120.722 ft <sup>2</sup>
Surface Horizontal Width:	21.0645 ft
Surface Average Height:	5.73108 ft

**Method: gle/morgenstern-price**

FS	0.997623
Center:	-36.576, 119.856
Radius:	106.334
Left Slip Surface Endpoint:	-0.000, 20.011
Right Slip Surface Endpoint:	21.064, 30.500
Left Slope Intercept:	-0.000 25.250
Right Slope Intercept:	21.064 30.500
Resisting Moment:	659150 lb-ft
Driving Moment:	660721 lb-ft
Resisting Horizontal Force:	5610.69 lb
Driving Horizontal Force:	5624.06 lb
Total Slice Area:	120.722 ft <sup>2</sup>
Surface Horizontal Width:	21.0645 ft
Surface Average Height:	5.73108 ft

#### ◆ LDCC - Kpe - 0.5\*Kh - 2H:1V LDCC Batter Angle

**Method: spencer**

FS	1.051050
Center:	-36.576, 119.856
Radius:	106.334
Left Slip Surface Endpoint:	-0.000, 20.011
Right Slip Surface Endpoint:	21.064, 30.500
Left Slope Intercept:	-0.000 25.250
Right Slope Intercept:	21.064 30.500
Resisting Moment:	727841 lb-ft
Driving Moment:	692490 lb-ft
Resisting Horizontal Force:	6213.67 lb
Driving Horizontal Force:	5911.88 lb
Total Slice Area:	120.722 ft <sup>2</sup>
Surface Horizontal Width:	21.0645 ft
Surface Average Height:	5.73108 ft

**Method: gle/morgenstern-price**

FS	0.966542
Center:	-36.576, 119.856
Radius:	106.334
Left Slip Surface Endpoint:	-0.000, 20.011
Right Slip Surface Endpoint:	21.064, 30.500
Left Slope Intercept:	-0.000 25.250
Right Slope Intercept:	21.064 30.500
Resisting Moment:	669321 lb-ft
Driving Moment:	692490 lb-ft
Resisting Horizontal Force:	5692.98 lb
Driving Horizontal Force:	5890.05 lb
Total Slice Area:	120.722 ft <sup>2</sup>
Surface Horizontal Width:	21.0645 ft
Surface Average Height:	5.73108 ft

# Global Minimum Coordinates

## All other Scenarios

**Method: spencer**

X	Y
24.7337	30.5
25.4951	29.6864
26.2581	28.8713
27.0211	28.0561
27.7841	27.241
28.8687	26.0822
30.0908	24.8984
31.0943	23.9698
32.0945	23.0644
33.0957	22.3905
34.0976	21.7433
34.9362	21.2017
35.7748	20.6601
36.6133	20.1185
37.4519	19.5768
38.2905	19.0352
39.1291	18.4936
40.8062	17.9029
42.109	17.5026
43.4118	17.2986
44.4203	17.613
45.4252	17.9824
46.4257	18.4175
47.4263	19.1744
47.7606	21.0628
48.0949	22.9508
48.4291	24.8379
48.7632	26.725
49.0973	28.6124
49.4315	30.5

**Method: gle/morgenstern-price**

X	Y
11.2952	30.5
12.3245	29.3728
13.9276	27.6172
15.5307	25.8615
17.1338	24.1059
18.737	22.3503
20.631	20.276
22.4579	18.2754
23.7424	16.8688
25.0268	15.4622
26.2311	14.1434
27.4792	12.7766
28.7056	11.4335
29.932	10.0905
31.497	8.82941
33.062	8.34474
34.9108	7.77219
36.7595	8.0863
38.3024	8.34885
39.8453	10.0303
40.9883	11.2834
42.1312	12.5364
43.4776	14.0124
45.1162	15.8101
45.8717	17.8815
46.6272	20.0972
47.5476	22.82
48.4679	25.556
49.231	27.9912
50	30.5

## Global Minimum Support Data

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### All Open Scenarios

No Supports Present

# Valid and Invalid Surfaces

## ◆ LDCC - Master Scenario

### **Method: spencer**

Number of Valid Surfaces:	275
Number of Invalid Surfaces:	49845

### Error Codes

Error Code -108 reported for 768 surfaces  
 Error Code -109 reported for 14 surfaces  
 Error Code -111 reported for 2420 surfaces  
 Error Code -112 reported for 15 surfaces  
 Error Code -121 reported for 42 surfaces  
 Error Code -124 reported for 4 surfaces  
 Error Code -145 reported for 1082 surfaces  
 Error Code -1000 reported for 45500 surfaces

### **Method: gle/morgenstern-price**

Number of Valid Surfaces:	351
Number of Invalid Surfaces:	49769

### Error Codes

Error Code -108 reported for 871 surfaces  
 Error Code -109 reported for 14 surfaces  
 Error Code -111 reported for 3573 surfaces  
 Error Code -112 reported for 20 surfaces  
 Error Code -121 reported for 42 surfaces  
 Error Code -124 reported for 4 surfaces  
 Error Code -145 reported for 1082 surfaces  
 Error Code -1000 reported for 44163 surfaces

## ◆ LDCC - Kp - 2H:1V LDCC Batter Angle

### **Method: spencer**

Number of Valid Surfaces:	1508
Number of Invalid Surfaces:	4

### Error Codes

Error Code -108 reported for 1 surface  
 Error Code -111 reported for 3 surfaces

### **Method: gle/morgenstern-price**

Number of Valid Surfaces:	1509
Number of Invalid Surfaces:	3

### Error Codes

Error Code -111 reported for 3 surfaces

## ◆ LDCC - Kpe - 0.6\*Kh - 2H:1V LDCC Batter Angle

### **Method: spencer**

Number of Valid Surfaces:	1338
Number of Invalid Surfaces:	0

**Method: gle/morgenstern-price**

Number of Valid Surfaces:	1337
Number of Invalid Surfaces:	1

**Error Codes**

Error Code -111 reported for 1 surface

## ◆ **LDCC - Kpe - 0.5\*Kh - 2H:1V LDCC Batter Angle**

**Method: spencer**

Number of Valid Surfaces:	1342
Number of Invalid Surfaces:	0

**Method: gle/morgenstern-price**

Number of Valid Surfaces:	1341
Number of Invalid Surfaces:	1

**Error Codes**

Error Code -111 reported for 1 surface

## **Error Code Descriptions**

The following errors were encountered during the computation:

-108 = Total driving moment or total driving force < 0.1. This is to limit the calculation of extremely high safety factors if the driving force is very small (0.1 is an arbitrary number).

-109 = Soiltype for slice base not located. This error should occur very rarely, if at all. It may occur if a very low number of slices is combined with certain soil geometries, such that the midpoint of a slice base is actually outside the soil region, even though the slip surface is wholly within the soil region.

-111 = Safety factor equation did not converge

-112 = The coefficient M-Alpha =  $\cos(\alpha)(1+\tan(\alpha)\tan(\phi))/F < 0.2$  for the final iteration of the safety factor calculation. This screens out some slip surfaces which may not be valid in the context of the analysis, in particular, deep seated slip surfaces with many high negative base angle slices in the passive zone.

-121 = Concave failure surface, only convex surfaces have been defined as being allowed.

-124 = A slice has a width less than the minimum acceptable value.

-145 = Slip surface was clipped vertically by a weak layer in a region of compression. Such a surface cannot be evaluated using Limit Equilibrium. For more information, see Help Documentation on weak layers.

-1000 = No valid slip surface is generated

# Slice Data

## ◆ LDCC - Master Scenario

**Global Minimum Query (spencer) - Safety Factor: 11.5408**

Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [deg]	Base Material	Base Cohesion [psf]	Base Friction Angle [deg]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	0.761395	10.8402	-46.8971	LDCC	5760	0	499.099	5760	449.584	0	449.584	-83.7113	-83.7113
2	0.762987	32.6099	-46.8931	LDCC	5760	0	499.099	5760	475.274	0	475.274	-57.9461	-57.9461
3	0.762987	54.3781	-46.8931	LDCC	5760	0	499.099	5760	501.05	0	501.05	-32.1704	-32.1704
4	0.763008	76.1487	-46.8931	LDCC	5760	0	499.099	5760	526.827	0	526.827	-6.39352	-6.39352
5	0.542313	67.3582	-46.8931	LDCC	5760	0	499.099	5760	548.876	0	548.876	15.6561	15.6561
6	0.542313	78.3556	-46.8931	LDCC	5760	0	499.099	5760	567.198	0	567.198	33.9777	33.9777
7	0.61105	100.812	-44.0869	LDCC	5760	0	499.099	5760	545.658	0	545.658	62.2177	62.2177
8	0.61105	113.47	-44.0869	LDCC	5760	0	499.099	5760	564.544	0	564.544	81.1043	81.1043
9	0.501755	102.449	-42.7815	LDCC	5760	0	499.099	5760	563.954	0	563.954	102.082	102.082
10	0.501755	110.603	-42.7815	LDCC	5760	0	499.099	5760	578.828	0	578.828	116.957	116.957
11	0.500094	118.262	-42.1524	LDCC	5760	0	499.099	5760	585.381	0	585.381	133.58	133.58
12	0.500094	126.186	-42.1524	LDCC	5760	0	499.099	5760	599.91	0	599.91	148.11	148.11
13	0.0259679	6.766	-33.9418	LDCC	5760	0	499.099	5760	512.088	0	512.088	176.179	176.179
14	0.487626	141.138	-33.9418	ESU 3B	0	34	16.3632	188.844	279.973	0	279.973	268.961	268.961
15	0.487626	169.012	-33.9418	ESU 3B	0	34	19.5947	226.139	335.264	0	335.264	322.077	322.077
16	0.500952	202.267	-32.8616	ESU 3B	0	34	22.8513	263.722	390.984	0	390.984	376.222	376.222
17	0.500952	230.904	-32.8616	ESU 3B	0	34	26.0866	301.06	446.341	0	446.341	429.489	429.489
18	0.419288	215.277	-32.8575	ESU 3B	0	34	29.0582	335.355	497.184	0	497.184	478.416	478.416
19	0.419288	235.336	-32.8575	ESU 3B	0	34	31.7658	366.603	543.511	0	543.511	522.995	522.995
20	0.419288	255.395	-32.8575	ESU 3B	0	34	34.4734	397.851	589.839	0	589.839	567.573	567.573
21	0.419288	275.455	-32.8575	ESU 3B	0	34	37.181	429.099	636.165	0	636.165	612.15	612.15
22	0.838577	611.088	-32.8575	ESU 3B	0	34	41.2425	475.971	705.656	0	705.656	679.019	679.019
23	0.419288	335.633	-32.8575	ESU 3B	0	34	45.304	522.844	775.148	0	775.148	745.887	745.887
24	0.419288	355.692	-32.8575	ESU 3B	0	34	48.0116	554.092	821.476	0	821.476	790.466	790.466
25	0.419288	375.752	-32.8575	ESU 3B	0	34	50.7192	585.34	867.801	0	867.801	835.043	835.043
26	0.419288	395.879	-32.8575	ESU 3B	0	34	53.436	616.694	914.287	0	914.287	879.774	879.774
27	0.838577	856.278	-32.8575	ESU 3B	0	34	57.7904	666.948	988.792	0	988.792	951.466	951.466
28	0.838577	931.641	-19.4009	ESU 3B	0	34	63.6288	734.327	1088.68	0	1088.68	1066.28	1066.28
29	0.838577	995.129	-19.4009	ESU 3B	0	34	67.9648	784.368	1162.87	0	1162.87	1138.93	1138.93
30	0.211375	260.739	-17.0807	ESU 3B	0	34	70.7774	816.828	1211	0	1211	1189.25	1189.25
31	0.545701	691.412	-17.0807	ESU 4D	700	35	136.906	1580	1256.78	0	1256.78	1214.71	1214.71
32	0.545701	718.132	-17.0807	ESU 4D	700	35	139.824	1613.68	1304.87	0	1304.87	1261.9	1261.9
33	0.651388	888.044	-8.9025	ESU 4D	700	35	142.576	1645.44	1350.23	0	1350.23	1327.9	1327.9
34	0.651388	917.807	-8.9025	ESU 4D	700	35	145.315	1677.05	1395.37	0	1395.37	1372.61	1372.61
35	0.504266	723.208	17.3162	ESU 4D	700	35	146.687	1692.88	1417.99	0	1417.99	1463.72	1463.72
36	0.504266	725.607	17.3162	ESU 4D	700	35	146.977	1696.24	1422.77	0	1422.77	1468.59	1468.59
37	0.612025	883.168	20.1842	ESU 4D	700	35	147.212	1698.94	1426.63	0	1426.63	1480.75	1480.75
38	0.392848	568.2	20.1842	ESU 3B	0	34	85.3382	984.871	1460.13	0	1460.13	1491.5	1491.5
39	0.50027	724.837	23.4998	ESU 3B	0	34	85.7292	989.383	1466.82	0	1466.82	1504.1	1504.1
40	0.50027	725.404	23.4998	ESU 3B	0	34	85.7963	990.158	1467.97	0	1467.97	1505.28	1505.28
41	0.500279	721.355	37.1088	ESU 3B	0	34	86.4865	998.123	1479.78	0	1479.78	1545.21	1545.21
42	0.500279	709.74	37.1088	ESU 3B	0	34	85.0939	982.052	1455.95	0	1455.95	1520.33	1520.33
43	0.334363	431.256	79.959	ESU 3B	0	34	97.7515	1128.13	1672.53	0	1672.53	2224.59	2224.59
44	0.334296	358.58	79.9591	ESU 3B	0	34	81.2948	938.207	1390.95	0	1390.95	1850.08	1850.08
45	0.334134	285.877	79.9591	ESU 3B	0	34	64.8434	748.345	1109.47	0	1109.47	1475.68	1475.68
46	0.216431	146.477	79.9591	ESU 3B	0	34	51.2929	591.961	877.619	0	877.619	1167.31	1167.31
47	0.117703	66.1056	79.9591	ESU 3C	0	38	46.1231	532.298	681.31	0	681.31	941.799	941.799
48	0.334134	130.097	79.9609	ESU 3C	0	38	31.9767	369.037	472.346	0	472.346	652.975	652.975
49	0.0817943	18.8751	79.9617	ESU 3C	0	38	18.9523	218.725	279.956	0	279.956	387.021	387.021
50	0.25234	25.1801	79.9617	ESU 3D	0	42	8.81057	101.681	112.929	0	112.929	162.701	162.701

**Global Minimum Query (gle/morgenstern-price) - Safety Factor: 12.221**

Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [deg]	Base Material	Base Cohesion [psf]	Base Friction Angle [deg]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	1.02925	20.3025	-47.6	LDCC	5760	0	471.32	5760	527.136	0	527.136	10.9749	10.9749
2	0.801562	43.9359	-47.6	LDCC	5760	0	471.32	5760	546.435	0	546.435	30.2742	30.2742
3	0.801562	68.5629	-47.6	LDCC	5760	0	471.32	5760	563.166	0	563.166	47.0047	47.0047
4	0.801562	93.1899	-47.6	LDCC	5760	0	471.32	5760	579.875	0	579.875	63.7142	63.7142
5	0.801562	117.817	-47.6	LDCC	5760	0	471.32	5760	596.685	0	596.685	80.5238	80.5238
6	0.801562	142.444	-47.6	LDCC	5760	0	471.32	5760	613.715	0	613.715	97.5546	97.5546
7	0.801562	167.071	-47.6	LDCC	5760	0	471.32	5760	631.086	0	631.086	114.925	114.925
8	0.801562	191.698	-47.6	LDCC	5760	0	471.32	5760	648.912	0	648.912	132.751	132.751
9	0.801562	216.325	-47.6	LDCC	5760	0	471.32	5760	667.305	0	667.305	151.144	151.144
10	0.947007	287.313	-47.6	LDCC	5760	0	471.32	5760	688.154	0	688.154	171.993	171.993
11	0.947007	321.688	-47.6	LDCC	5760	0	471.32	5760	711.793	0	711.793	195.632	195.632
12	0.252074	91.4195	-47.5989	LDCC	5760	0	471.32	5760	727.335	0	727.335	211.193	211.193
13	0.787427	328.422	-47.5989	ESU 3B	0	34	19.1317	233.808	346.635	0	346.635	325.684	325.684
14	0.787427	406.508	-47.5989	ESU 3B	0	34	24.4982	299.393	443.869	0	443.869	417.041	417.041
15	0.399396	236.035	-47.5989	ESU 3B	0	34	28.5198	348.54	516.732	0	516.732	485.5	485.5
16	0.885063	601.073	-47.5989	ESU 4D	700	35	95.0615	1161.75	659.441	0	659.441	555.339	555.339
17	0.642229	505.977	-47.5989	ESU 4D	700	35	101.058	1235.03	764.107	0	764.107	653.438	653.438
18	0.642229	564.696	-47.5989	ESU 4D	700	35	106.101	1296.65	852.112	0	852.112	735.921	735.921
19	1.20424	1218.2	-47.5989	ESU 4D	700	35	113.417	1386.07	979.802	0	979.802	855.599	855.599
20	0.624052	725.447	-47.5989	ESU 4D	700	35	121.786	1488.35	1125.88	0	1125.88	992.516	992.516
21	0.624052	796.398	-47.5989	ESU 4D	700	35	128.119	1565.74	1236.4	0	1236.4	1096.1	1096.1
22	0.613216	851.684	-47.5989	ESU 4D	700	35	134.431	1642.88	1346.57	0	1346.57	1199.36	1199.36
23	0.613216	920.194	-47.5989	ESU 4D	700	35	140.732	1719.89	1456.55	0	1456.55	1302.43	1302.43
24	1.22643	2045.91	-47.5989	ESU 4D	700	35	150.298	1836.79	1623.5	0	1623.5	1458.91	1458.91
25	0.782506	1437.05	-38.8611	ESU 4D	700	35	160.412	1960.4	1800.04	0	1800.04	1670.78	1670.78
26	0.782506	1525.58	-38.8611	ESU 4D	700	35	167.301	2044.58	1920.26	0	1920.26	1785.45	1785.45
27	0.782506	1594.36	-17.2075	ESU 4D	700	35	173.671	2122.43	2031.45	0	2031.45	1977.67	1977.67
28	0.782506	1643.4	-17.2075	ESU 4D	700	35	177.986	2175.17	2106.76	0	2106.76	2051.64	2051.64
29	0.92437	2004.51	-17.2075	ESU 4D	700	35	182.753	2233.43	2189.97	0	2189.97	2133.37	2133.37
30	0.92437	2072.94	-17.2075	ESU 4D	700	35	187.988	2297.4	2281.32	0	2281.32	2223.1	2223.1
31	1.84874	4244.63	9.6428	ESU 4D	700	35	193.146	2360.44	2371.36	0	2371.36	2404.18	2404.18
32	0.77144	1789.11	9.65748	ESU 4D	700	35	195.543	2389.73	2413.19	0	2413.19	2446.46	2446.46
33	0.77144	1799.73	9.65748	ESU 4D	700	35	196.905	2406.37	2436.94	0	2436.94	2470.45	2470.45
34	0.77144	1778.56	47.4613	ESU 4D	700	35	195.416	2388.18	2410.97	0	2410.97	2623.94	2623.94
35	0.77144	1723.87	47.4613	ESU 4D	700	35	190.742	2331.06	2329.4	0	2329.4	2537.28	2537.28
36	1.14298	2453.02	47.6299	ESU 4D	700	35	184.777	2258.16	2225.28	0	2225.28	2427.85	2427.85
37	1.14298	2331.87	47.6299	ESU 4D	700	35	177.508	2169.33	2098.42	0	2098.42	2293.02	2293.02
38	0.673201	1316.76	47.6299	ESU 4D	700	35	171.664	2097.91	1996.43	0	1996.43	2184.62	2184.62
39	0.673201	1274.73	47.6299	ESU 4D	700	35	167.309	2044.68	1920.4	0	1920.4	2103.82	2103.82
40	0.81926	1494.57	47.6522	ESU 4D	700	35	162.465	1985.48	1835.86	0	1835.86	2014.11	2014.11
41	0.81926	1433.23	47.6522	ESU 4D	700	35	157.218	1921.36	1744.28	0	1744.28	1916.78	1916.78
42	0.739677	1183.43	69.9603	ESU 4D	700	35	139.447	1704.18	1434.12	0	1434.12	1816.42	1816.42
43	0.0158611	23.5593	69.9603	ESU 3B	0	34	80.8038	987.503	1464.03	0	1464.03	1685.56	1685.56
44	0.755538	1039.33	71.1711	ESU 3B	0	34	73.6567	900.159	1334.54	0	1334.54	1550.55	1550.55
45	0.920322	1039.55	71.3246	ESU 3B	0	34	58.8485	719.188	1066.24	0	1066.24	1240.35	1240.35
46	0.920322	756.321	71.4083	ESU 3B	0	34	41.5608	507.914	753.014	0	753.014	876.569	876.569
47	0.158001	100.408	72.6001	ESU 3B	0	34	31.2852	382.336	566.836	0	566.836	666.668	666.668
48	0.605125	288.136	72.6001	ESU 3C	0	38	26.1937	320.113	409.726	0	409.726	493.311	493.311
49	0.33205	90.5486	72.9589	ESU 3C	0	38	14.7162	179.847	230.195	0	230.195	278.206	278.206
50	0.436945	43.6012	72.9589	ESU 3D	0	42	5.98175	73.103	81.1894	0	81.1894	100.705	100.705

## ◆ **LDCC - K<sub>p</sub> - 2H:1V LDCC Batter Angle**

**Global Minimum Query (spencer) - Safety Factor: 1.09525**

Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [deg]	Base Material	Base Cohesion [psf]	Base Friction Angle [deg]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	0.0224715	8.24696	19.9251	LDCC	5760	0	5259.07	5760	176207	0	176207	174301	174301
2	0.434028	159.207	20.0062	ESU 3B	0	34	305.718	334.838	496.418	0	496.418	385.108	385.108
3	0.434028	158.905	20.254	ESU 3B	0	34	306.469	335.66	497.638	0	497.638	384.551	384.551
4	0.434028	158.496	20.5022	ESU 3B	0	34	307.027	336.271	498.542	0	498.542	383.736	383.736
5	0.434028	157.98	20.7508	ESU 3B	0	34	307.387	336.666	499.127	0	499.127	382.663	382.663
6	0.434028	157.357	20.9998	ESU 3B	0	34	307.548	336.842	499.389	0	499.389	381.333	381.333
7	0.434028	156.625	21.2493	ESU 3B	0	34	307.504	336.794	499.318	0	499.318	379.741	379.741
8	0.434028	155.785	21.4991	ESU 3B	0	34	307.253	336.519	498.911	0	498.911	377.886	377.886
9	0.434028	154.836	21.7494	ESU 3B	0	34	306.791	336.013	498.159	0	498.159	375.765	375.765
10	0.434028	153.777	22.0001	ESU 3B	0	34	306.113	335.27	497.058	0	497.058	373.379	373.379
11	0.434028	152.607	22.2513	ESU 3B	0	34	305.215	334.287	495.601	0	495.601	370.726	370.726
12	0.434028	151.326	22.5029	ESU 3B	0	34	304.094	333.059	493.78	0	493.78	367.802	367.802
13	0.434028	149.934	22.755	ESU 3B	0	34	302.745	331.582	491.59	0	491.59	364.607	364.607
14	0.434028	148.43	23.0075	ESU 3B	0	34	301.163	329.849	489.022	0	489.022	361.139	361.139
15	0.434028	146.813	23.2606	ESU 3B	0	34	299.344	327.857	486.068	0	486.068	357.394	357.394
16	0.434028	145.082	23.5141	ESU 3B	0	34	297.284	325.6	482.722	0	482.722	353.373	353.373
17	0.434028	143.238	23.768	ESU 3B	0	34	294.976	323.072	478.974	0	478.974	349.07	349.07
18	0.434028	141.278	24.0225	ESU 3B	0	34	292.415	320.268	474.816	0	474.816	344.487	344.487
19	0.434028	139.203	24.2775	ESU 3B	0	34	289.598	317.182	470.241	0	470.241	339.619	339.619
20	0.434028	137.012	24.533	ESU 3B	0	34	286.517	313.808	465.239	0	465.239	334.466	334.466
21	0.434028	134.704	24.789	ESU 3B	0	34	283.167	310.139	459.801	0	459.801	329.025	329.025
22	0.434028	132.279	25.0456	ESU 3B	0	34	279.543	306.17	453.915	0	453.915	323.291	323.291
23	0.434028	129.735	25.3027	ESU 3B	0	34	275.638	301.893	447.576	0	447.576	317.267	317.267
24	0.434028	127.072	25.5603	ESU 3B	0	34	271.447	297.302	440.769	0	440.769	310.945	310.945
25	0.434028	124.29	25.8185	ESU 3B	0	34	266.961	292.389	433.485	0	433.485	304.324	304.324
26	0.434028	121.386	26.0773	ESU 3B	0	34	262.176	287.148	425.714	0	425.714	297.405	297.405
27	0.434028	118.362	26.3366	ESU 3B	0	34	257.082	281.569	417.443	0	417.443	290.181	290.181
28	0.434028	115.215	26.5965	ESU 3B	0	34	251.673	275.645	408.66	0	408.66	282.651	282.651
29	0.434028	111.945	26.857	ESU 3B	0	34	245.942	269.368	399.354	0	399.354	274.812	274.812
30	0.434028	108.551	27.1181	ESU 3B	0	34	239.879	262.728	389.511	0	389.511	266.663	266.663
31	0.434028	105.033	27.3798	ESU 3B	0	34	233.479	255.718	379.118	0	379.118	258.198	258.198
32	0.434028	101.389	27.6422	ESU 3B	0	34	226.73	248.326	368.158	0	368.158	249.414	249.414
33	0.434028	97.6179	27.9051	ESU 3B	0	34	219.625	240.544	356.621	0	356.621	240.31	240.31
34	0.434028	93.7198	28.1687	ESU 3B	0	34	212.154	232.362	344.49	0	344.49	230.882	230.882
35	0.434028	89.6931	28.433	ESU 3B	0	34	204.307	223.767	331.748	0	331.748	221.128	221.128
36	0.434028	85.5372	28.6979	ESU 3B	0	34	196.074	214.75	318.38	0	318.38	211.042	211.042
37	0.434028	81.2508	28.9635	ESU 3B	0	34	187.445	205.299	304.369	0	304.369	200.623	200.623
38	0.434028	76.8331	29.2298	ESU 3B	0	34	178.408	195.401	289.693	0	289.693	189.863	189.863
39	0.434028	72.2831	29.4968	ESU 3B	0	34	168.951	185.044	274.34	0	274.34	178.764	178.764
40	0.434028	67.5996	29.7644	ESU 3B	0	34	159.064	174.215	258.283	0	258.283	167.318	167.318
41	0.434028	62.7816	30.0328	ESU 3B	0	34	148.732	162.899	241.508	0	241.508	155.523	155.523
42	0.434028	57.828	30.3019	ESU 3B	0	34	137.943	151.082	223.989	0	223.989	143.375	143.375
43	0.434028	52.7378	30.5718	ESU 3B	0	34	126.683	138.75	205.705	0	205.705	130.868	130.868
44	0.434028	47.5097	30.8424	ESU 3B	0	34	114.937	125.885	186.633	0	186.633	118.001	118.001
45	0.434028	42.1426	31.1138	ESU 3B	0	34	102.691	112.472	166.747	0	166.747	104.766	104.766
46	0.434028	36.6353	31.386	ESU 3B	0	34	89.9271	98.4927	146.021	0	146.021	91.1599	91.1599
47	0.434028	30.9866	31.6589	ESU 3B	0	34	76.6297	83.9287	124.429	0	124.429	77.1778	77.1778
48	0.434028	25.1952	31.9327	ESU 3B	0	34	62.7808	68.7607	101.942	0	101.942	62.8146	62.8146
49	0.434028	18.8625	32.2072	ESU 3B	0	34	47.364	51.8754	76.9085	0	76.9085	47.0735	47.0735
50	0.434028	6.89604	32.4826	ESU 3B	0	34	18.3354	20.0819	29.7726	0	29.7726	18.0995	18.0995

**Global Minimum Query (gle/morgenstern-price) - Safety Factor: 1.01993**

Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [deg]	Base Material	Base Cohesion [psf]	Base Friction Angle [deg]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	0.0247702	9.09061	20.6006	LDCC	5760	0	5647.45	5760	173032	0	173032	170909	170909
2	0.422447	154.807	20.6844	ESU 3B	0	34	213.159	217.407	322.32	0	322.32	241.84	241.84
3	0.422447	154.244	20.9296	ESU 3B	0	34	217.343	221.675	328.646	0	328.646	245.522	245.522
4	0.422447	153.581	21.1752	ESU 3B	0	34	221.97	226.394	335.642	0	335.642	249.657	249.657
5	0.422447	152.817	21.4211	ESU 3B	0	34	227.016	231.54	343.272	0	343.272	254.209	254.209
6	0.422447	151.95	21.6675	ESU 3B	0	34	232.448	237.081	351.487	0	351.487	259.138	259.138
7	0.422447	150.982	21.9143	ESU 3B	0	34	238.227	242.975	360.225	0	360.225	264.389	264.389
8	0.422447	149.91	22.1615	ESU 3B	0	34	244.305	249.174	369.415	0	369.415	269.908	269.908
9	0.422447	148.736	22.4092	ESU 3B	0	34	250.628	255.623	378.977	0	378.977	275.629	275.629
10	0.422447	147.457	22.6573	ESU 3B	0	34	257.133	262.258	388.813	0	388.813	281.477	281.477
11	0.422447	146.074	22.9058	ESU 3B	0	34	263.751	269.008	398.822	0	398.822	287.378	287.378
12	0.422447	144.586	23.1548	ESU 3B	0	34	270.409	275.798	408.888	0	408.888	293.243	293.243
13	0.422447	142.992	23.4043	ESU 3B	0	34	277.024	282.545	418.889	0	418.889	298.985	298.985
14	0.422447	141.292	23.6543	ESU 3B	0	34	283.511	289.161	428.699	0	428.699	304.517	304.517
15	0.422447	139.486	23.9047	ESU 3B	0	34	289.781	295.556	438.18	0	438.18	309.738	309.738
16	0.422447	137.571	24.1556	ESU 3B	0	34	295.743	301.637	447.196	0	447.196	314.559	314.559
17	0.422447	135.549	24.407	ESU 3B	0	34	301.302	307.307	455.602	0	455.602	318.881	318.881
18	0.422447	133.418	24.6589	ESU 3B	0	34	306.366	312.472	463.26	0	463.26	322.613	322.613
19	0.422447	131.178	24.9113	ESU 3B	0	34	310.843	317.038	470.028	0	470.028	325.665	325.665
20	0.422447	128.828	25.1642	ESU 3B	0	34	314.642	320.913	475.774	0	475.774	327.955	327.955
21	0.422447	126.367	25.4177	ESU 3B	0	34	317.679	324.01	480.365	0	480.365	329.4	329.4
22	0.422447	123.794	25.6717	ESU 3B	0	34	319.871	326.246	483.68	0	483.68	329.931	329.931
23	0.422447	121.11	25.9262	ESU 3B	0	34	321.146	327.546	485.606	0	485.606	329.484	329.484
24	0.422447	118.313	26.1813	ESU 3B	0	34	321.436	327.842	486.045	0	486.045	328.009	328.009
25	0.422447	115.402	26.437	ESU 3B	0	34	320.685	327.076	484.911	0	484.911	325.463	325.463
26	0.422447	112.376	26.6932	ESU 3B	0	34	318.845	325.2	482.127	0	482.127	321.812	321.812
27	0.422447	109.236	26.95	ESU 3B	0	34	315.881	322.176	477.645	0	477.645	317.043	317.043
28	0.422447	105.98	27.2073	ESU 3B	0	34	311.765	317.978	471.423	0	471.423	311.147	311.147
29	0.422447	102.607	27.4653	ESU 3B	0	34	306.487	312.595	463.44	0	463.44	304.129	304.129
30	0.422447	99.1167	27.7239	ESU 3B	0	34	300.044	306.024	453.698	0	453.698	296.012	296.012
31	0.422447	95.508	27.9831	ESU 3B	0	34	292.449	298.278	442.215	0	442.215	286.828	286.828
32	0.422447	91.78	28.2429	ESU 3B	0	34	283.726	289.381	429.025	0	429.025	276.619	276.619
33	0.422447	87.932	28.5033	ESU 3B	0	34	273.91	279.369	414.181	0	414.181	265.44	265.44
34	0.422447	83.9631	28.7644	ESU 3B	0	34	263.047	268.29	397.757	0	397.757	253.358	253.358
35	0.422447	79.8723	29.0262	ESU 3B	0	34	251.197	256.203	379.837	0	379.837	240.446	240.446
36	0.422447	75.6587	29.2886	ESU 3B	0	34	238.424	243.176	360.524	0	360.524	226.789	226.789
37	0.422447	71.3213	29.5517	ESU 3B	0	34	224.804	229.284	339.928	0	339.928	212.472	212.472
38	0.422447	66.8593	29.8155	ESU 3B	0	34	210.416	214.61	318.172	0	318.172	197.59	197.59
39	0.422447	62.2716	30.08	ESU 3B	0	34	195.35	199.243	295.389	0	295.389	182.24	182.24
40	0.422447	57.5572	30.3451	ESU 3B	0	34	179.692	183.273	271.714	0	271.714	166.521	166.521
41	0.422447	52.7151	30.611	ESU 3B	0	34	163.535	166.794	247.283	0	247.283	150.527	150.527
42	0.422447	47.7442	30.8777	ESU 3B	0	34	146.969	149.898	222.234	0	222.234	134.353	134.353
43	0.422447	42.6435	31.1451	ESU 3B	0	34	130.082	132.675	196.699	0	196.699	118.088	118.088
44	0.422447	37.4118	31.4132	ESU 3B	0	34	112.96	115.211	170.807	0	170.807	101.82	101.82
45	0.422447	32.0481	31.6821	ESU 3B	0	34	95.6782	97.5851	144.676	0	144.676	85.6251	85.6251
46	0.422447	26.5512	31.9518	ESU 3B	0	34	78.3094	79.8701	118.412	0	118.412	69.5708	69.5708
47	0.422447	20.9199	32.2223	ESU 3B	0	34	60.9143	62.1283	92.1089	0	92.1089	53.7161	53.7161
48	0.422447	15.153	32.4936	ESU 3B	0	34	43.5435	44.4113	65.8424	0	65.8424	38.1091	38.1091
49	0.422447	9.24929	32.7657	ESU 3B	0	34	26.2357	26.7586	39.6712	0	39.6712	22.7856	22.7856
50	0.422447	3.20594	33.0386	ESU 3B	0	34	9.0125	9.19212	13.6279	0	13.6279	7.76645	7.76645

## ◆ **LDCC - Kpe - 0.6\*Kh - 2H:1V LDCC Batter Angle**

**Global Minimum Query (spencer) - Safety Factor: 1.0857**

Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [deg]	Base Material	Base Cohesion [psf]	Base Friction Angle [deg]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	0.0753355	27.616	20.1554	LDCC	5760	0	5305.33	5760	42507.2	0	42507.2	40559.9	40559.9
2	0.42835	156.666	20.2853	ESU 3B	0	34	330.799	359.149	532.459	0	532.459	410.19	410.19
3	0.42835	156.255	20.5315	ESU 3B	0	34	331.708	360.135	533.924	0	533.924	409.695	409.695
4	0.42835	155.741	20.7782	ESU 3B	0	34	332.414	360.902	535.06	0	535.06	408.932	408.932
5	0.42835	155.122	21.0253	ESU 3B	0	34	332.914	361.445	535.864	0	535.864	407.901	407.901
6	0.42835	154.4	21.2727	ESU 3B	0	34	333.203	361.759	536.329	0	536.329	406.601	406.601
7	0.42835	153.572	21.5206	ESU 3B	0	34	333.276	361.838	536.447	0	536.447	405.028	405.028
8	0.42835	152.638	21.769	ESU 3B	0	34	333.13	361.679	536.211	0	536.211	403.178	403.178
9	0.42835	151.598	22.0177	ESU 3B	0	34	332.759	361.276	535.614	0	535.614	401.051	401.051
10	0.42835	150.452	22.2669	ESU 3B	0	34	332.158	360.624	534.647	0	534.647	398.643	398.643
11	0.42835	149.199	22.5165	ESU 3B	0	34	331.322	359.716	533.302	0	533.302	395.952	395.952
12	0.42835	147.837	22.7666	ESU 3B	0	34	330.246	358.548	531.57	0	531.57	392.974	392.974
13	0.42835	146.367	23.0172	ESU 3B	0	34	328.924	357.113	529.442	0	529.442	389.706	389.706
14	0.42835	144.789	23.2682	ESU 3B	0	34	327.351	355.405	526.91	0	526.91	386.146	386.146
15	0.42835	143.1	23.5196	ESU 3B	0	34	325.52	353.417	523.962	0	523.962	382.289	382.289
16	0.42835	141.301	23.7716	ESU 3B	0	34	323.426	351.144	520.591	0	520.591	378.135	378.135
17	0.42835	139.392	24.0241	ESU 3B	0	34	321.062	348.577	516.787	0	516.787	373.679	373.679
18	0.42835	137.371	24.277	ESU 3B	0	34	318.42	345.709	512.535	0	512.535	368.916	368.916
19	0.42835	135.237	24.5305	ESU 3B	0	34	315.496	342.534	507.828	0	507.828	363.846	363.846
20	0.42835	132.991	24.7844	ESU 3B	0	34	312.281	339.043	502.653	0	502.653	358.462	358.462
21	0.42835	130.631	25.0389	ESU 3B	0	34	308.768	335.229	496.997	0	496.997	352.761	352.761
22	0.42835	128.157	25.2939	ESU 3B	0	34	304.948	331.082	490.849	0	490.849	346.74	346.74
23	0.42835	125.568	25.5495	ESU 3B	0	34	300.813	326.593	484.194	0	484.194	340.395	340.395
24	0.42835	122.863	25.8056	ESU 3B	0	34	296.357	321.755	477.02	0	477.02	333.72	333.72
25	0.42835	120.041	26.0622	ESU 3B	0	34	291.569	316.556	469.313	0	469.313	326.713	326.713
26	0.42835	117.103	26.3195	ESU 3B	0	34	286.439	310.987	461.058	0	461.058	319.37	319.37
27	0.42835	114.046	26.5772	ESU 3B	0	34	280.96	305.038	452.238	0	452.238	311.683	311.683
28	0.42835	110.871	26.8356	ESU 3B	0	34	275.12	298.698	442.837	0	442.837	303.649	303.649
29	0.42835	107.575	27.0946	ESU 3B	0	34	268.909	291.954	432.839	0	432.839	295.264	295.264
30	0.42835	104.16	27.3541	ESU 3B	0	34	262.316	284.796	422.227	0	422.227	286.522	286.522
31	0.42835	100.623	27.6143	ESU 3B	0	34	255.328	277.21	410.981	0	410.981	277.417	277.417
32	0.42835	96.9638	27.8751	ESU 3B	0	34	247.936	269.184	399.081	0	399.081	267.944	267.944
33	0.42835	93.1816	28.1365	ESU 3B	0	34	240.125	260.704	386.509	0	386.509	258.098	258.098
34	0.42835	89.2755	28.3986	ESU 3B	0	34	231.883	251.755	373.242	0	373.242	247.871	247.871
35	0.42835	85.2445	28.6613	ESU 3B	0	34	223.194	242.322	359.256	0	359.256	237.257	237.257
36	0.42835	81.0877	28.9247	ESU 3B	0	34	214.046	232.39	344.533	0	344.533	226.253	226.253
37	0.42835	76.8041	29.1887	ESU 3B	0	34	204.422	221.941	329.041	0	329.041	214.846	214.846
38	0.42835	72.3928	29.4534	ESU 3B	0	34	194.307	210.959	312.761	0	312.761	203.036	203.036
39	0.42835	67.8527	29.7188	ESU 3B	0	34	183.683	199.425	295.659	0	295.659	190.807	190.807
40	0.42835	63.1828	29.985	ESU 3B	0	34	172.533	187.319	277.712	0	277.712	178.161	178.161
41	0.42835	58.3822	30.2518	ESU 3B	0	34	160.837	174.621	258.886	0	258.886	165.082	165.082
42	0.42835	53.4496	30.5194	ESU 3B	0	34	148.577	161.31	239.151	0	239.151	151.565	151.565
43	0.42835	48.3841	30.7877	ESU 3B	0	34	135.73	147.362	218.473	0	218.473	137.601	137.601
44	0.42835	43.1845	31.0567	ESU 3B	0	34	122.275	132.754	196.816	0	196.816	123.181	123.181
45	0.42835	37.8497	31.3265	ESU 3B	0	34	108.189	117.461	174.143	0	174.143	108.294	108.294
46	0.42835	32.3785	31.5971	ESU 3B	0	34	93.4457	101.454	150.412	0	150.412	92.9307	92.9307
47	0.42835	26.7698	31.8685	ESU 3B	0	34	78.0207	84.7071	125.583	0	125.583	77.0793	77.0793
48	0.42835	21.0223	32.1407	ESU 3B	0	34	61.8851	67.1886	99.6111	0	99.6111	60.7295	60.7295
49	0.42835	15.1348	32.4137	ESU 3B	0	34	45.0096	48.8669	72.4481	0	72.4481	43.8691	43.8691
50	0.42835	6.64119	32.6875	ESU 3B	0	34	20.0441	21.7619	32.2633	0	32.2633	19.4014	19.4014

**Global Minimum Query (gle/morgenstern-price) - Safety Factor: 0.997623**

Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [deg]	Base Material	Base Cohesion [psf]	Base Friction Angle [deg]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	0.0753355	27.616	20.1554	LDCC	5760	0	5773.72	5760	53388.7	0	53388.7	51269.5	51269.5
2	0.42835	156.666	20.2853	ESU 3B	0	34	225.493	224.957	333.512	0	333.512	250.165	250.165
3	0.42835	156.255	20.5315	ESU 3B	0	34	229.294	228.749	339.135	0	339.135	253.262	253.262
4	0.42835	155.741	20.7782	ESU 3B	0	34	233.526	232.971	345.393	0	345.393	256.787	256.787
5	0.42835	155.122	21.0253	ESU 3B	0	34	238.173	237.607	352.267	0	352.267	260.72	260.72
6	0.42835	154.4	21.2727	ESU 3B	0	34	243.21	242.632	359.717	0	359.717	265.027	265.027
7	0.42835	153.572	21.5206	ESU 3B	0	34	248.608	248.017	367.699	0	367.699	269.667	269.667
8	0.42835	152.638	21.769	ESU 3B	0	34	254.326	253.721	376.156	0	376.156	274.593	274.593
9	0.42835	151.598	22.0177	ESU 3B	0	34	260.317	259.698	385.019	0	385.019	279.75	279.75
10	0.42835	150.452	22.2669	ESU 3B	0	34	266.528	265.894	394.205	0	394.205	285.074	285.074
11	0.42835	149.199	22.5165	ESU 3B	0	34	272.896	272.247	403.623	0	403.623	290.494	290.494
12	0.42835	147.837	22.7666	ESU 3B	0	34	279.352	278.688	413.172	0	413.172	295.935	295.935
13	0.42835	146.367	23.0172	ESU 3B	0	34	285.82	285.141	422.739	0	422.739	301.314	301.314
14	0.42835	144.789	23.2682	ESU 3B	0	34	292.222	291.527	432.208	0	432.208	306.55	306.55
15	0.42835	143.1	23.5196	ESU 3B	0	34	298.469	297.76	441.447	0	441.447	311.547	311.547
16	0.42835	141.301	23.7716	ESU 3B	0	34	304.474	303.75	450.327	0	450.327	316.218	316.218
17	0.42835	139.392	24.0241	ESU 3B	0	34	310.143	309.406	458.713	0	458.713	320.473	320.473
18	0.42835	137.371	24.277	ESU 3B	0	34	315.385	314.635	466.466	0	466.466	324.216	324.216
19	0.42835	135.237	24.5305	ESU 3B	0	34	320.105	319.344	473.448	0	473.448	327.362	327.362
20	0.42835	132.991	24.7844	ESU 3B	0	34	324.213	323.442	479.522	0	479.522	329.822	329.822
21	0.42835	130.631	25.0389	ESU 3B	0	34	327.618	326.839	484.558	0	484.558	331.517	331.517
22	0.42835	128.157	25.2939	ESU 3B	0	34	330.236	329.451	488.432	0	488.432	332.373	332.373
23	0.42835	125.568	25.5495	ESU 3B	0	34	331.988	331.199	491.023	0	491.023	332.32	332.32
24	0.42835	122.863	25.8056	ESU 3B	0	34	332.801	332.01	492.226	0	492.226	331.304	331.304
25	0.42835	120.041	26.0622	ESU 3B	0	34	332.611	331.82	491.943	0	491.943	329.271	329.271
26	0.42835	117.103	26.3195	ESU 3B	0	34	331.363	330.575	490.099	0	490.099	326.189	326.189
27	0.42835	114.046	26.5772	ESU 3B	0	34	329.011	328.229	486.621	0	486.621	322.028	322.028
28	0.42835	110.871	26.8356	ESU 3B	0	34	325.523	324.749	481.46	0	481.46	316.773	316.773
29	0.42835	107.575	27.0946	ESU 3B	0	34	320.875	320.112	474.585	0	474.585	310.423	310.423
30	0.42835	104.16	27.3541	ESU 3B	0	34	315.057	314.308	465.98	0	465.98	302.99	302.99
31	0.42835	100.623	27.6143	ESU 3B	0	34	308.072	307.34	455.65	0	455.65	294.496	294.496
32	0.42835	96.9638	27.8751	ESU 3B	0	34	299.936	299.223	443.617	0	443.617	284.976	284.976
33	0.42835	93.1816	28.1365	ESU 3B	0	34	290.675	289.984	429.918	0	429.918	274.474	274.474
34	0.42835	89.2755	28.3986	ESU 3B	0	34	280.327	279.661	414.614	0	414.614	263.051	263.051
35	0.42835	85.2445	28.6613	ESU 3B	0	34	268.943	268.304	397.776	0	397.776	250.77	250.77
36	0.42835	81.0877	28.9247	ESU 3B	0	34	256.582	255.972	379.494	0	379.494	237.709	237.709
37	0.42835	76.8041	29.1887	ESU 3B	0	34	243.313	242.735	359.871	0	359.871	223.951	223.951
38	0.42835	72.3928	29.4534	ESU 3B	0	34	229.214	228.669	339.015	0	339.015	209.578	209.578
39	0.42835	67.8527	29.7188	ESU 3B	0	34	214.365	213.855	317.053	0	317.053	194.688	194.688
40	0.42835	63.1828	29.985	ESU 3B	0	34	198.853	198.38	294.111	0	294.111	179.373	179.373
41	0.42835	58.3822	30.2518	ESU 3B	0	34	182.768	182.334	270.322	0	270.322	163.727	163.727
42	0.42835	53.4496	30.5194	ESU 3B	0	34	166.201	165.806	245.818	0	245.818	147.842	147.842
43	0.42835	48.3841	30.7877	ESU 3B	0	34	149.24	148.885	220.731	0	220.731	131.81	131.81
44	0.42835	43.1845	31.0567	ESU 3B	0	34	131.969	131.655	195.187	0	195.187	115.714	115.714
45	0.42835	37.8497	31.3265	ESU 3B	0	34	114.47	114.198	169.305	0	169.305	99.6338	99.6338
46	0.42835	32.3785	31.5971	ESU 3B	0	34	96.8162	96.5861	143.195	0	143.195	83.6397	83.6397
47	0.42835	26.7698	31.8685	ESU 3B	0	34	79.0726	78.8846	116.951	0	116.951	67.7932	67.7932
48	0.42835	21.0223	32.1407	ESU 3B	0	34	61.2933	61.1476	90.655	0	90.655	52.1452	52.1452
49	0.42835	15.1348	32.4137	ESU 3B	0	34	43.5217	43.4182	64.3702	0	64.3702	36.7359	36.7359
50	0.42835	6.64119	32.6875	ESU 3B	0	34	18.8914	18.8465	27.9411	0	27.9411	15.8188	15.8188

## ◆ **LDCC - Kpe - 0.5\*Kh - 2H:1V LDCC Batter Angle**

**Global Minimum Query (spencer) - Safety Factor: 1.05105**

Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [deg]	Base Material	Base Cohesion [psf]	Base Friction Angle [deg]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	0.0753355	27.616	20.1554	LDCC	5760	0	5480.23	5760	46298.6	0	46298.6	44287.1	44287.1
2	0.42835	156.666	20.2853	ESU 3B	0	34	345.89	363.548	538.983	0	538.983	411.135	411.135
3	0.42835	156.255	20.5315	ESU 3B	0	34	346.881	364.589	540.524	0	540.524	410.613	410.613
4	0.42835	155.741	20.7782	ESU 3B	0	34	347.659	365.407	541.739	0	541.739	409.827	409.827
5	0.42835	155.122	21.0253	ESU 3B	0	34	348.222	365.999	542.617	0	542.617	408.77	408.77
6	0.42835	154.4	21.2727	ESU 3B	0	34	348.566	366.36	543.151	0	543.151	407.442	407.442
7	0.42835	153.572	21.5206	ESU 3B	0	34	348.684	366.484	543.336	0	543.336	405.841	405.841
8	0.42835	152.638	21.769	ESU 3B	0	34	348.573	366.368	543.162	0	543.162	403.961	403.961
9	0.42835	151.598	22.0177	ESU 3B	0	34	348.227	366.004	542.624	0	542.624	401.806	401.806
10	0.42835	150.452	22.2669	ESU 3B	0	34	347.642	365.389	541.712	0	541.712	399.368	399.368
11	0.42835	149.199	22.5165	ESU 3B	0	34	346.81	364.515	540.415	0	540.415	396.644	396.644
12	0.42835	147.837	22.7666	ESU 3B	0	34	345.728	363.377	538.73	0	538.73	393.636	393.636
13	0.42835	146.367	23.0172	ESU 3B	0	34	344.389	361.97	536.642	0	536.642	390.336	390.336
14	0.42835	144.789	23.2682	ESU 3B	0	34	342.787	360.286	534.146	0	534.146	386.744	386.744
15	0.42835	143.1	23.5196	ESU 3B	0	34	340.914	358.318	531.23	0	531.23	382.857	382.857
16	0.42835	141.301	23.7716	ESU 3B	0	34	338.767	356.061	527.883	0	527.883	378.67	378.67
17	0.42835	139.392	24.0241	ESU 3B	0	34	336.337	353.507	524.094	0	524.094	374.178	374.178
18	0.42835	137.371	24.277	ESU 3B	0	34	333.616	350.647	519.855	0	519.855	369.383	369.383
19	0.42835	135.237	24.5305	ESU 3B	0	34	330.598	347.475	515.154	0	515.154	364.279	364.279
20	0.42835	132.991	24.7844	ESU 3B	0	34	327.276	343.983	509.975	0	509.975	358.861	358.861
21	0.42835	130.631	25.0389	ESU 3B	0	34	323.64	340.162	504.311	0	504.311	353.128	353.128
22	0.42835	128.157	25.2939	ESU 3B	0	34	319.683	336.003	498.146	0	498.146	347.074	347.074
23	0.42835	125.568	25.5495	ESU 3B	0	34	315.396	331.497	491.465	0	491.465	340.694	340.694
24	0.42835	122.863	25.8056	ESU 3B	0	34	310.77	326.635	484.256	0	484.256	333.987	333.987
25	0.42835	120.041	26.0622	ESU 3B	0	34	305.796	321.407	476.506	0	476.506	326.948	326.948
26	0.42835	117.103	26.3195	ESU 3B	0	34	300.463	315.802	468.196	0	468.196	319.571	319.571
27	0.42835	114.046	26.5772	ESU 3B	0	34	294.762	309.81	459.312	0	459.312	311.852	311.852
28	0.42835	110.871	26.8356	ESU 3B	0	34	288.681	303.418	449.836	0	449.836	303.788	303.788
29	0.42835	107.575	27.0946	ESU 3B	0	34	282.21	296.617	439.752	0	439.752	295.371	295.371
30	0.42835	104.16	27.3541	ESU 3B	0	34	275.336	289.392	429.041	0	429.041	286.599	286.599
31	0.42835	100.623	27.6143	ESU 3B	0	34	268.047	281.731	417.683	0	417.683	277.466	277.466
32	0.42835	96.9638	27.8751	ESU 3B	0	34	260.33	273.62	405.658	0	405.658	267.965	267.965
33	0.42835	93.1816	28.1365	ESU 3B	0	34	252.173	265.046	392.947	0	392.947	258.093	258.093
34	0.42835	89.2755	28.3986	ESU 3B	0	34	243.559	255.993	379.527	0	379.527	247.842	247.842
35	0.42835	85.2445	28.6613	ESU 3B	0	34	234.476	246.446	365.371	0	365.371	237.205	237.205
36	0.42835	81.0877	28.9247	ESU 3B	0	34	224.907	236.388	350.458	0	350.458	226.177	226.177
37	0.42835	76.8041	29.1887	ESU 3B	0	34	214.834	225.801	334.764	0	334.764	214.753	214.753
38	0.42835	72.3928	29.4534	ESU 3B	0	34	204.241	214.668	318.26	0	318.26	202.924	202.924
39	0.42835	67.8527	29.7188	ESU 3B	0	34	193.112	202.97	300.916	0	300.916	190.683	190.683
40	0.42835	63.1828	29.985	ESU 3B	0	34	181.424	190.686	282.705	0	282.705	178.023	178.023
41	0.42835	58.3822	30.2518	ESU 3B	0	34	169.159	177.795	263.593	0	263.593	164.935	164.935
42	0.42835	53.4496	30.5194	ESU 3B	0	34	156.296	164.275	243.547	0	243.547	151.411	151.411
43	0.42835	48.3841	30.7877	ESU 3B	0	34	142.811	150.102	222.534	0	222.534	137.443	137.443
44	0.42835	43.1845	31.0567	ESU 3B	0	34	128.681	135.25	200.516	0	200.516	123.023	123.023
45	0.42835	37.8497	31.3265	ESU 3B	0	34	113.881	119.695	177.455	0	177.455	108.141	108.141
46	0.42835	32.3785	31.5971	ESU 3B	0	34	98.3835	103.406	153.306	0	153.306	92.7871	92.7871
47	0.42835	26.7698	31.8685	ESU 3B	0	34	82.1615	86.3558	128.028	0	128.028	76.9495	76.9495
48	0.42835	21.0223	32.1407	ESU 3B	0	34	65.1841	68.5117	101.573	0	101.573	60.6185	60.6185
49	0.42835	15.1348	32.4137	ESU 3B	0	34	47.4198	49.8406	73.8918	0	73.8918	43.7824	43.7824
50	0.42835	6.64119	32.6875	ESU 3B	0	34	22.2958	23.434	34.7423	0	34.7423	20.4355	20.4355

**Global Minimum Query (gle/morgenstern-price) - Safety Factor: 0.966542**

Slice Number	Width [ft]	Weight [lbs]	Angle of Slice Base [deg]	Base Material	Base Cohesion [psf]	Base Friction Angle [deg]	Shear Stress [psf]	Shear Strength [psf]	Base Normal Stress [psf]	Pore Pressure [psf]	Effective Normal Stress [psf]	Base Vertical Stress [psf]	Effective Vertical Stress [psf]
1	0.0753355	27.616	20.1554	LDCC	5760	0	5959.39	5760	57282.9	0	57282.9	55095.5	55095.5
2	0.42835	156.666	20.2853	ESU 3B	0	34	235.599	227.716	337.602	0	337.602	250.521	250.521
3	0.42835	156.255	20.5315	ESU 3B	0	34	239.73	231.709	343.523	0	343.523	253.742	253.742
4	0.42835	155.741	20.7782	ESU 3B	0	34	244.3	236.126	350.071	0	350.071	257.376	257.376
5	0.42835	155.122	21.0253	ESU 3B	0	34	249.291	240.95	357.224	0	357.224	261.404	261.404
6	0.42835	154.4	21.2727	ESU 3B	0	34	254.677	246.156	364.943	0	364.943	265.788	265.788
7	0.42835	153.572	21.5206	ESU 3B	0	34	260.425	251.712	373.179	0	373.179	270.486	270.486
8	0.42835	152.638	21.769	ESU 3B	0	34	266.492	257.576	381.873	0	381.873	275.451	275.451
9	0.42835	151.598	22.0177	ESU 3B	0	34	272.831	263.703	390.955	0	390.955	280.626	280.626
10	0.42835	150.452	22.2669	ESU 3B	0	34	279.383	270.035	400.343	0	400.343	285.948	285.948
11	0.42835	149.199	22.5165	ESU 3B	0	34	286.084	276.512	409.946	0	409.946	291.35	291.35
12	0.42835	147.837	22.7666	ESU 3B	0	34	292.863	283.064	419.66	0	419.66	296.753	296.753
13	0.42835	146.367	23.0172	ESU 3B	0	34	299.641	289.616	429.374	0	429.374	302.078	302.078
14	0.42835	144.789	23.2682	ESU 3B	0	34	306.337	296.088	438.968	0	438.968	307.24	307.24
15	0.42835	143.1	23.5196	ESU 3B	0	34	312.862	302.394	448.318	0	448.318	312.154	312.154
16	0.42835	141.301	23.7716	ESU 3B	0	34	319.123	308.446	457.29	0	457.29	316.728	316.728
17	0.42835	139.392	24.0241	ESU 3B	0	34	325.028	314.153	465.752	0	465.752	320.877	320.877
18	0.42835	137.371	24.277	ESU 3B	0	34	330.481	319.424	473.565	0	473.565	324.507	324.507
19	0.42835	135.237	24.5305	ESU 3B	0	34	335.386	324.165	480.595	0	480.595	327.535	327.535
20	0.42835	132.991	24.7844	ESU 3B	0	34	339.65	328.286	486.705	0	486.705	329.877	329.877
21	0.42835	130.631	25.0389	ESU 3B	0	34	343.182	331.7	491.764	0	491.764	331.452	331.452
22	0.42835	128.157	25.2939	ESU 3B	0	34	345.895	334.322	495.653	0	495.653	332.194	332.194
23	0.42835	125.568	25.5495	ESU 3B	0	34	347.707	336.073	498.249	0	498.249	332.033	332.033
24	0.42835	122.863	25.8056	ESU 3B	0	34	348.545	336.883	499.45	0	499.45	330.915	330.915
25	0.42835	120.041	26.0622	ESU 3B	0	34	348.342	336.687	499.16	0	499.16	328.793	328.793
26	0.42835	117.103	26.3195	ESU 3B	0	34	347.041	335.43	497.297	0	497.297	325.632	325.632
27	0.42835	114.046	26.5772	ESU 3B	0	34	344.598	333.068	493.795	0	493.795	321.404	321.404
28	0.42835	110.871	26.8356	ESU 3B	0	34	340.975	329.567	488.603	0	488.603	316.098	316.098
29	0.42835	107.575	27.0946	ESU 3B	0	34	336.15	324.903	481.688	0	481.688	309.712	309.712
30	0.42835	104.16	27.3541	ESU 3B	0	34	330.111	319.066	473.034	0	473.034	302.256	302.256
31	0.42835	100.623	27.6143	ESU 3B	0	34	322.86	312.058	462.644	0	462.644	293.754	293.754
32	0.42835	96.9638	27.8751	ESU 3B	0	34	314.412	303.892	450.539	0	450.539	284.241	284.241
33	0.42835	93.1816	28.1365	ESU 3B	0	34	304.792	294.594	436.753	0	436.753	273.76	273.76
34	0.42835	89.2755	28.3986	ESU 3B	0	34	294.038	284.2	421.344	0	421.344	262.368	262.368
35	0.42835	85.2445	28.6613	ESU 3B	0	34	282.202	272.76	404.384	0	404.384	250.131	250.131
36	0.42835	81.0877	28.9247	ESU 3B	0	34	269.343	260.331	385.957	0	385.957	237.121	237.121
37	0.42835	76.8041	29.1887	ESU 3B	0	34	255.528	246.979	366.163	0	366.163	223.419	223.419
38	0.42835	72.3928	29.4534	ESU 3B	0	34	240.838	232.78	345.111	0	345.111	209.11	209.11
39	0.42835	67.8527	29.7188	ESU 3B	0	34	225.353	217.813	322.92	0	322.92	194.283	194.283
40	0.42835	63.1828	29.985	ESU 3B	0	34	209.162	202.164	299.721	0	299.721	179.034	179.034
41	0.42835	58.3822	30.2518	ESU 3B	0	34	192.356	185.92	275.638	0	275.638	163.451	163.451
42	0.42835	53.4496	30.5194	ESU 3B	0	34	175.026	169.17	250.805	0	250.805	147.627	147.627
43	0.42835	48.3841	30.7877	ESU 3B	0	34	157.264	152.002	225.352	0	225.352	131.65	131.65
44	0.42835	43.1845	31.0567	ESU 3B	0	34	139.156	134.5	199.404	0	199.404	115.603	115.603
45	0.42835	37.8497	31.3265	ESU 3B	0	34	120.784	116.743	173.079	0	173.079	99.5644	99.5644
46	0.42835	32.3785	31.5971	ESU 3B	0	34	102.226	98.806	146.486	0	146.486	83.6031	83.6031
47	0.42835	26.7698	31.8685	ESU 3B	0	34	83.5482	80.7528	119.721	0	119.721	67.7806	67.7806
48	0.42835	21.0223	32.1407	ESU 3B	0	34	64.8069	62.6386	92.8654	0	92.8654	52.148	52.148
49	0.42835	15.1348	32.4137	ESU 3B	0	34	46.0476	44.5069	65.9843	0	65.9843	36.7462	36.7462
50	0.42835	6.64119	32.6875	ESU 3B	0	34	20.0043	19.335	28.6653	0	28.6653	15.8289	15.8289

# Interslice Data

## ◆ LDCC - Master Scenario

**Global Minimum Query (spencer) - Safety Factor: 11.5408**

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [deg]
1	24.7337	30.5	0	0	0
2	25.4951	29.6864	745.776	-74.5776	-5.71059
3	26.2581	28.8713	1514	-151.4	-5.71059
4	27.0211	28.0561	2303.24	-230.324	-5.71059
5	27.7841	27.241	3113.51	-311.351	-5.71059
6	28.3264	26.6616	3702.19	-370.219	-5.71059
7	28.8687	26.0822	4301.49	-430.149	-5.71059
8	29.4797	25.4903	4929.42	-492.942	-5.71059
9	30.0908	24.8984	5568.54	-556.854	-5.71059
10	30.5925	24.4341	6080.83	-608.083	-5.71059
11	31.0943	23.9698	6600.02	-660.002	-5.71059
12	31.5944	23.5171	7114.62	-711.462	-5.71059
13	32.0945	23.0644	7635.8	-763.58	-5.71059
14	32.1205	23.0469	7657.71	-765.771	-5.71059
15	32.6081	22.7187	7757.57	-775.757	-5.71059
16	33.0957	22.3905	7877.15	-787.715	-5.71059
17	33.5967	22.0669	8015.12	-801.512	-5.71059
18	34.0976	21.7433	8172.63	-817.263	-5.71059
19	34.5169	21.4725	8319.46	-831.946	-5.71059
20	34.9362	21.2017	8479.96	-847.996	-5.71059
21	35.3555	20.9309	8654.15	-865.415	-5.71059
22	35.7748	20.6601	8842.02	-884.202	-5.71059
23	36.6133	20.1185	9258.8	-925.88	-5.71059
24	37.0326	19.8476	9487.71	-948.771	-5.71059
25	37.4519	19.5768	9730.31	-973.031	-5.71059
26	37.8712	19.306	9986.58	-998.658	-5.71059
27	38.2905	19.0352	10256.6	-1025.66	-5.71059
28	39.1291	18.4936	10840.6	-1084.06	-5.71059
29	39.9676	18.1983	11215.5	-1121.55	-5.71059
30	40.8062	17.9029	11615.9	-1161.59	-5.71059
31	41.0176	17.838	11709.5	-1170.95	-5.71059
32	41.5633	17.6703	11994.9	-1199.49	-5.71059
33	42.109	17.5026	12290	-1229	-5.71059
34	42.7604	17.4006	12520.7	-1252.07	-5.71059
35	43.4118	17.2986	12757.7	-1275.77	-5.71059
36	43.916	17.4558	12608.8	-1260.88	-5.71059
37	44.4203	17.613	12459.2	-1245.92	-5.71059
38	45.0323	17.838	12228.3	-1222.83	-5.71059
39	45.4252	17.9824	12051	-1205.1	-5.71059
40	45.9255	18.1999	11774.8	-1177.48	-5.71059
41	46.4257	18.4175	11498.4	-1149.84	-5.71059
42	46.926	18.7959	10981.6	-1098.16	-5.71059
43	47.4263	19.1744	10473.1	-1047.31	-5.71059
44	47.7606	21.0628	7347.45	-734.745	-5.71059
45	48.0949	22.9508	4748.52	-474.852	-5.71059
46	48.4291	24.8379	2676.52	-267.652	-5.71059
47	48.6455	26.0602	1614.88	-161.488	-5.71059
48	48.7632	26.725	1167.41	-116.741	-5.71059
49	49.0973	28.6124	286.568	-28.6568	-5.71059
50	49.1791	29.0745	158.759	-15.8759	-5.71059
51	49.4315	30.5	0	0	0

**Global Minimum Query (gle/morgenstern-price) - Safety Factor: 12.221**

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [deg]
1	11.2952	30.5	0	0	0
2	12.3245	29.3728	1079.28	-9.00575	-0.478078
3	13.126	28.495	1936.74	-28.6739	-0.848216
4	13.9276	27.6172	2808.89	-59.5585	-1.21469
5	14.7291	26.7394	3695.71	-101.677	-1.57593
6	15.5307	25.8615	4597.28	-154.949	-1.93039
7	16.3323	24.9837	5513.81	-219.196	-2.27654
8	17.1338	24.1059	6445.58	-294.146	-2.6129
9	17.9354	23.2281	7393	-379.435	-2.93804
10	18.737	22.3503	8356.56	-474.608	-3.2506
11	19.684	21.3132	9516.59	-599.042	-3.60185
12	20.631	20.276	10701.1	-735.465	-3.93164
13	20.883	20	11020.7	-773.648	-4.01555
14	21.6705	19.1377	11334.7	-845.619	-4.26662
15	22.4579	18.2754	11736.7	-923.74	-4.5002
16	22.8573	17.838	11974.1	-965.869	-4.61168
17	23.7424	16.8688	12697.4	-1075.43	-4.84122
18	24.3846	16.1655	13299.7	-1161.75	-4.99221
19	25.0268	15.4622	13967.2	-1253.82	-5.12963
20	26.2311	14.1434	15395.9	-1441.67	-5.34957
21	26.8551	13.46	16241.3	-1547.73	-5.44362
22	27.4792	12.7766	17166.2	-1660.11	-5.52379
23	28.0924	12.1051	18152.9	-1776.33	-5.58882
24	28.7056	11.4335	19217.3	-1897.85	-5.64009
25	29.932	10.0905	21582.1	-2154.5	-5.70084
26	30.7145	9.45994	22842.6	-2284.15	-5.71032
27	31.497	8.82941	24184.3	-2412.61	-5.69694
28	32.2795	8.58708	24812.5	-2459.43	-5.6607
29	33.062	8.34474	25462.3	-2497.41	-5.6018
30	33.9864	8.05846	26258.2	-2529.9	-5.50329
31	34.9108	7.77219	27085	-2547.87	-5.37397
32	36.7595	8.0863	26697.2	-2347.81	-5.02579
33	37.531	8.21758	26531.3	-2249.62	-4.84658
34	38.3024	8.34885	26363.3	-2143.55	-4.64839
35	39.0738	9.18959	24487.1	-1897.9	-4.43191
36	39.8453	10.0303	22675.8	-1664.42	-4.19802
37	40.9883	11.2834	20098.6	-1342.47	-3.82135
38	42.1312	12.5364	17672.1	-1053.48	-3.41151
39	42.8044	13.2744	16314.3	-899.552	-3.15603
40	43.4776	14.0124	15009.6	-757.994	-2.89102
41	44.2969	14.9113	13492.6	-602.496	-2.55678
42	45.1162	15.8101	12053.5	-465.385	-2.21109
43	45.8558	17.838	9248.48	-305.251	-1.89039
44	45.8717	17.8815	9186.1	-302.076	-1.88344
45	46.6272	20.0972	6284.79	-169.906	-1.54858
46	47.5476	22.82	3435.76	-67.9393	-1.13283
47	48.4679	25.556	1413.77	-17.5357	-0.710632
48	48.6259	26.0602	1132.92	-12.6094	-0.637676
49	49.231	27.9912	357.607	-2.23058	-0.357379
50	49.5631	29.0745	113.123	-0.401105	-0.203155
51	50	30.5	0	0	0

## ◆ **LDCC - Kp - 2H:1V LDCC Batter Angle**

**Global Minimum Query (spencer) - Safety Factor: 1.09525**

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [deg]
1	-6.03151e-05	20.0033	10155.3	0	0
2	0.0224112	20.0114	8601.51	318.843	2.12288
3	0.456439	20.1694	8390.05	311.004	2.12288
4	0.890467	20.3296	8177.01	303.107	2.12288
5	1.32449	20.4919	7962.51	295.156	2.12288
6	1.75852	20.6563	7746.69	287.156	2.12288
7	2.19255	20.8229	7529.68	279.112	2.12288
8	2.62658	20.9917	7311.62	271.029	2.12288
9	3.06061	21.1627	7092.64	262.912	2.12288
10	3.49463	21.3358	6872.9	254.766	2.12288
11	3.92866	21.5112	6652.55	246.598	2.12288
12	4.36269	21.6888	6431.75	238.414	2.12288
13	4.79672	21.8666	6210.66	230.218	2.12288
14	5.23074	22.0506	5989.45	222.018	2.12288
15	5.66477	22.2349	5768.29	213.82	2.12288
16	6.0988	22.4215	5547.36	205.631	2.12288
17	6.53283	22.6103	5326.86	197.457	2.12288
18	6.96686	22.8015	5106.97	189.306	2.12288
19	7.40088	22.9949	4887.89	181.185	2.12288
20	7.83491	23.1907	4669.83	173.102	2.12288
21	8.26894	23.3888	4453.01	165.065	2.12288
22	8.70297	23.5892	4237.64	157.082	2.12288
23	9.13699	23.7921	4023.96	149.161	2.12288
24	9.57102	23.9972	3812.19	141.311	2.12288
25	10.005	24.2048	3602.59	133.542	2.12289
26	10.4391	24.4148	3395.41	125.862	2.12288
27	10.8731	24.6272	3190.92	118.282	2.12289
28	11.3071	24.8421	2989.37	110.811	2.12289
29	11.7412	25.0594	2791.07	103.46	2.12288
30	12.1752	25.2792	2596.29	96.2399	2.12288
31	12.6092	25.5015	2405.34	89.1618	2.12288
32	13.0432	25.7263	2218.54	82.2373	2.12288
33	13.4773	25.9536	2036.21	75.4785	2.12288
34	13.9113	26.1834	1858.68	68.8979	2.12288
35	14.3453	26.4158	1686.31	62.5084	2.12288
36	14.7794	26.6508	1519.45	56.3235	2.12289
37	15.2134	26.8884	1358.5	50.3571	2.12288
38	15.6474	27.1287	1203.83	44.6237	2.12287
39	16.0814	27.3715	1055.85	39.1383	2.12287
40	16.5155	27.6171	914.979	33.9167	2.12288
41	16.9495	27.8653	781.663	28.9749	2.12288
42	17.3835	28.1162	656.354	24.3299	2.12288
43	17.8175	28.3698	539.523	19.9991	2.12287
44	18.2516	28.6262	431.663	16.001	2.12288
45	18.6856	28.8854	333.286	12.3543	2.12288
46	19.1196	29.1474	244.924	9.07891	2.12288
47	19.5537	29.4121	167.134	6.19536	2.12288
48	19.9877	29.6798	100.492	3.72507	2.12289
49	20.4217	29.9503	45.6016	1.69037	2.12288
50	20.8557	30.2237	3.96754	0.14707	2.12289
51	21.2898	30.5	0	0	0

**Global Minimum Query (gle/morgenstern-price) - Safety Factor: 1.01993**

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [deg]
1	-6.03151e-05	20.0033	10155.3	0	0
2	0.0247098	20.0126	8403.69	3.15544	0.0215136
3	0.447157	20.1721	8261.8	55.9658	0.388118
4	0.869604	20.3337	8116.44	106.689	0.753098
5	1.29205	20.4973	7967.3	155.057	1.11493
6	1.7145	20.663	7814.04	200.812	1.47211
7	2.13694	20.8309	7656.38	243.707	1.82314
8	2.55939	21.0008	7494.04	283.514	2.16658
9	2.98184	21.1729	7326.77	320.02	2.50099
10	3.40429	21.3471	7154.37	353.034	2.82498
11	3.82673	21.5234	6976.66	382.391	3.13724
12	4.24918	21.7019	6793.51	407.952	3.4365
13	4.67163	21.8826	6604.86	429.608	3.72152
14	5.09407	22.0654	6410.67	447.283	3.99115
15	5.51652	22.2505	6211	460.937	4.24431
16	5.93897	22.4377	6005.95	470.567	4.47998
17	6.36141	22.6272	5795.69	476.209	4.69722
18	6.78386	22.8189	5580.46	477.939	4.89516
19	7.20631	23.0128	5360.57	475.874	5.07302
20	7.62875	23.209	5136.4	470.172	5.23012
21	8.0512	23.4075	4908.42	461.028	5.36582
22	8.47365	23.6082	4677.14	448.677	5.4796
23	8.8961	23.8113	4443.15	433.386	5.57102
24	9.31854	24.0166	4207.1	415.455	5.63973
25	9.74099	24.2243	3969.71	395.212	5.68546
26	10.1634	24.4344	3731.73	373.004	5.70802
27	10.5859	24.6468	3493.98	349.198	5.70735
28	11.0083	24.8616	3257.31	324.17	5.68341
29	11.4308	25.0788	3022.59	298.303	5.63634
30	11.8532	25.2983	2790.73	271.975	5.56627
31	12.2757	25.5204	2562.64	245.56	5.47354
32	12.6981	25.7448	2339.24	219.412	5.35845
33	13.1206	25.9717	2121.45	193.869	5.22148
34	13.543	26.2011	1910.17	169.24	5.06315
35	13.9655	26.433	1706.27	145.802	4.8841
36	14.3879	26.6675	1510.6	123.796	4.68501
37	14.8104	26.9044	1323.97	103.423	4.46664
38	15.2328	27.1439	1147.13	84.8424	4.22993
39	15.6552	27.386	980.784	68.1666	3.97579
40	16.0777	27.6307	825.584	53.4637	3.70522
41	16.5001	27.878	682.113	40.756	3.41934
42	16.9226	28.1279	550.889	30.0211	3.11929
43	17.345	28.3806	432.366	21.1939	2.8063
44	17.7675	28.6358	326.934	14.1693	2.48164
45	18.1899	28.8938	234.918	8.80567	2.14667
46	18.6124	29.1546	156.584	4.92839	1.80276
47	19.0348	29.418	92.1438	2.33454	1.45133
48	19.4573	29.6843	41.7623	0.797379	1.09383
49	19.8797	29.9534	5.56339	0.0710585	0.731772
50	20.3022	30.2253	-16.3593	-0.104689	0.366651
51	20.7246	30.5	0	0	0

## ◆ **LDCC - Kpe - 0.6\*Kh - 2H:1V LDCC Batter Angle**

**Global Minimum Query (spencer) - Safety Factor: 1.0857**

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [deg]
1	-6.03151e-05	20.0106	9232.1	0	0
2	0.0752752	20.0382	7665.19	815.098	6.06989
3	0.503625	20.1965	7486.44	796.09	6.06989
4	0.931974	20.357	7305.82	776.884	6.06989
5	1.36032	20.5195	7123.44	757.489	6.06988
6	1.78867	20.6841	6939.39	737.918	6.06988
7	2.21702	20.8509	6753.78	718.181	6.06989
8	2.64537	21.0198	6566.73	698.29	6.06988
9	3.07372	21.1909	6378.34	678.257	6.06988
10	3.50207	21.3641	6188.74	658.096	6.06989
11	3.93042	21.5395	5998.06	637.819	6.06988
12	4.35877	21.7171	5806.43	617.442	6.06989
13	4.78712	21.8968	5614	596.979	6.06988
14	5.21547	22.0788	5420.9	576.445	6.06988
15	5.64382	22.263	5227.28	555.857	6.06989
16	6.07217	22.4494	5033.32	535.231	6.06988
17	6.50052	22.6381	4839.17	514.586	6.06989
18	6.92887	22.829	4645.01	493.939	6.06988
19	7.35722	23.0222	4451.01	473.31	6.06989
20	7.78557	23.2177	4257.38	452.719	6.06988
21	8.21392	23.4155	4064.3	432.188	6.06989
22	8.64227	23.6156	3871.98	411.737	6.06988
23	9.07062	23.818	3680.64	391.39	6.06988
24	9.49897	24.0228	3490.5	371.172	6.0699
25	9.92732	24.2299	3301.8	351.106	6.06989
26	10.3557	24.4394	3114.79	331.219	6.06988
27	10.784	24.6513	2929.71	311.538	6.06988
28	11.2124	24.8656	2746.84	292.092	6.06988
29	11.6407	25.0823	2566.45	272.91	6.06988
30	12.0691	25.3014	2388.85	254.024	6.06987
31	12.4974	25.523	2214.32	235.466	6.0699
32	12.9258	25.7471	2043.2	217.269	6.06989
33	13.3541	25.9737	1875.82	199.47	6.06988
34	13.7825	26.2027	1712.52	182.105	6.06988
35	14.2108	26.4343	1553.67	165.213	6.06987
36	14.6392	26.6685	1399.64	148.835	6.06991
37	15.0675	26.9052	1250.85	133.013	6.06991
38	15.4959	27.1444	1107.71	117.791	6.06987
39	15.9242	27.3863	970.65	103.217	6.06991
40	16.3526	27.6309	840.132	89.3376	6.06988
41	16.7809	27.878	716.636	76.2054	6.06989
42	17.2093	28.1278	600.666	63.8733	6.06988
43	17.6376	28.3803	492.747	52.3975	6.06988
44	18.066	28.6356	393.433	41.8367	6.06988
45	18.4943	28.8935	303.304	32.2527	6.0699
46	18.9227	29.1542	222.97	23.7101	6.06989
47	19.351	29.4177	153.07	16.2771	6.06989
48	19.7794	29.684	94.2768	10.0252	6.0699
49	20.2077	29.9532	47.2969	5.02944	6.06989
50	20.6361	30.2251	12.8744	1.36903	6.06987
51	21.0644	30.5	0	0	0

**Global Minimum Query (gle/morgenstern-price) - Safety Factor: 0.997623**

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [deg]
1	-6.03151e-05	20.0106	9232.1	0	0
2	0.0752752	20.0382	7327.17	8.89308	0.0695406
3	0.503625	20.1965	7224.64	58.5723	0.464504
4	0.931974	20.357	7118.75	106.552	0.857528
5	1.36032	20.5195	7009.15	152.57	1.24698
6	1.78867	20.6841	6895.51	196.369	1.63122
7	2.21702	20.8509	6777.48	237.702	2.00867
8	2.64537	21.0198	6654.77	276.33	2.37776
9	3.07372	21.1909	6527.07	312.03	2.73697
10	3.50207	21.3641	6394.14	344.596	3.08483
11	3.93042	21.5395	6255.74	373.839	3.41989
12	4.35877	21.7171	6111.68	399.598	3.74083
13	4.78712	21.8968	5961.84	421.735	4.04631
14	5.21547	22.0788	5806.11	440.144	4.33513
15	5.64382	22.263	5644.47	454.75	4.60612
16	6.07217	22.4494	5476.95	465.516	4.85821
17	6.50052	22.6381	5303.63	472.44	5.09039
18	6.92887	22.829	5124.68	475.561	5.30176
19	7.35722	23.0222	4940.32	474.959	5.4915
20	7.78557	23.2177	4750.86	470.753	5.65885
21	8.21392	23.4155	4556.66	463.105	5.80319
22	8.64227	23.6156	4358.16	452.214	5.92396
23	9.07062	23.818	4155.88	438.317	6.02068
24	9.49897	24.0228	3950.39	421.686	6.09299
25	9.92732	24.2299	3742.33	402.622	6.1406
26	10.3557	24.4394	3532.38	381.454	6.16336
27	10.784	24.6513	3321.3	358.532	6.16118
28	11.2124	24.8656	3109.88	334.219	6.13404
29	11.6407	25.0823	2898.94	308.889	6.08205
30	12.0691	25.3014	2689.34	282.919	6.00544
31	12.4974	25.523	2481.95	256.68	5.90446
32	12.9258	25.7471	2277.67	230.534	5.7795
33	13.3541	25.9737	2077.37	204.825	5.63106
34	13.7825	26.2027	1881.94	179.875	5.45972
35	14.2108	26.4343	1692.24	155.976	5.26615
36	14.6392	26.6685	1509.12	133.385	5.05102
37	15.0675	26.9052	1333.36	112.323	4.81526
38	15.4959	27.1444	1165.73	92.9696	4.55982
39	15.9242	27.3863	1006.95	75.4586	4.28561
40	16.3526	27.6309	857.672	59.8804	3.99376
41	16.7809	27.878	718.486	46.2794	3.68547
42	17.2093	28.1278	589.932	34.6554	3.36196
43	17.6376	28.3803	472.479	24.9645	3.02454
44	18.066	28.6356	366.532	17.1222	2.67457
45	18.4943	28.8935	272.433	11.0064	2.31351
46	18.9227	29.1542	190.463	6.46089	1.94284
47	19.351	29.4177	120.846	3.29974	1.56409
48	19.7794	29.684	63.7589	1.31197	1.17881
49	20.2077	29.9532	19.3329	0.266114	0.788617
50	20.6361	30.2251	-12.333	-0.0850545	0.395134
51	21.0644	30.5	0	0	0

## ◆ **LDCC - Kpe - 0.5\*Kh - 2H:1V LDCC Batter Angle**

**Global Minimum Query (spencer) - Safety Factor: 1.05105**

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [deg]
1	-6.03151e-05	20.0106	9924.51	0	0
2	0.0752752	20.0382	8238.39	823.839	5.71059
3	0.503625	20.1965	8044.38	804.438	5.71059
4	0.931974	20.357	7848.46	784.846	5.71059
5	1.36032	20.5195	7650.74	765.074	5.71059
6	1.78867	20.6841	7451.33	745.133	5.71059
7	2.21702	20.8509	7250.35	725.035	5.71059
8	2.64537	21.0198	7047.92	704.792	5.71059
9	3.07372	21.1909	6844.16	684.416	5.71059
10	3.50207	21.3641	6639.21	663.921	5.71059
11	3.93042	21.5395	6433.21	643.321	5.71059
12	4.35877	21.7171	6226.29	622.629	5.71059
13	4.78712	21.8968	6018.61	601.861	5.71059
14	5.21547	22.0788	5810.32	581.032	5.71059
15	5.64382	22.263	5601.59	560.159	5.71059
16	6.07217	22.4494	5392.59	539.259	5.71059
17	6.50052	22.6381	5183.49	518.349	5.71059
18	6.92887	22.829	4974.49	497.449	5.71059
19	7.35722	23.0222	4765.77	476.577	5.71059
20	7.78557	23.2177	4557.53	455.753	5.71059
21	8.21392	23.4155	4349.99	434.999	5.71059
22	8.64227	23.6156	4143.37	414.337	5.71059
23	9.07062	23.818	3937.9	393.79	5.71059
24	9.49897	24.0228	3733.81	373.381	5.71059
25	9.92732	24.2299	3531.35	353.135	5.71059
26	10.3557	24.4394	3330.79	333.079	5.71059
27	10.784	24.6513	3132.4	313.24	5.71059
28	11.2124	24.8656	2936.45	293.645	5.71059
29	11.6407	25.0823	2743.25	274.325	5.71059
30	12.0691	25.3014	2553.11	255.311	5.71059
31	12.4974	25.523	2366.34	236.634	5.71059
32	12.9258	25.7471	2183.29	218.329	5.71059
33	13.3541	25.9737	2004.31	200.431	5.71059
34	13.7825	26.2027	1829.77	182.977	5.71059
35	14.2108	26.4343	1660.04	166.004	5.71059
36	14.6392	26.6685	1495.54	149.554	5.71059
37	15.0675	26.9052	1336.68	133.668	5.71059
38	15.4959	27.1444	1183.91	118.391	5.71059
39	15.9242	27.3863	1037.68	103.768	5.71059
40	16.3526	27.6309	898.486	89.8486	5.71059
41	16.7809	27.878	766.824	76.6824	5.71059
42	17.2093	28.1278	643.226	64.3226	5.71059
43	17.6376	28.3803	528.249	52.8249	5.71059
44	18.066	28.6356	422.473	42.2473	5.71059
45	18.4943	28.8935	326.512	32.6512	5.71059
46	18.9227	29.1542	241.005	24.1005	5.71059
47	19.351	29.4177	166.628	16.6628	5.71059
48	19.7794	29.684	104.087	10.4087	5.71059
49	20.2077	29.9532	54.1273	5.41273	5.71059
50	20.6361	30.2251	17.5321	1.75321	5.71059
51	21.0644	30.5	0	0	0

**Global Minimum Query (gle/morgenstern-price) - Safety Factor: 0.966542**

Slice Number	X coordinate [ft]	Y coordinate - Bottom [ft]	Interslice Normal Force [lbs]	Interslice Shear Force [lbs]	Interslice Force Angle [deg]
1	-6.03151e-05	20.0106	9924.51	0	0
2	0.0752752	20.0382	7896.56	8.87213	0.0643743
3	0.503625	20.1965	7781.22	58.3979	0.429996
4	0.931974	20.357	7662.34	106.168	0.793829
5	1.36032	20.5195	7539.58	151.923	1.15436
6	1.78867	20.6841	7412.6	195.412	1.51009
7	2.21702	20.8509	7281.07	236.392	1.85955
8	2.64537	21.0198	7144.68	274.633	2.2013
9	3.07372	21.1909	7003.17	309.918	2.53391
10	3.50207	21.3641	6856.26	342.05	2.85604
11	3.93042	21.5395	6703.75	370.851	3.16637
12	4.35877	21.7171	6545.47	396.167	3.46362
13	4.78712	21.8968	6381.28	417.87	3.74659
14	5.21547	22.0788	6211.1	435.865	4.01416
15	5.64382	22.263	6034.93	450.087	4.26524
16	6.07217	22.4494	5852.8	460.505	4.49883
17	6.50052	22.6381	5664.83	467.126	4.71399
18	6.92887	22.829	5471.19	469.997	4.90988
19	7.35722	23.0222	5272.12	469.203	5.08576
20	7.78557	23.2177	5067.95	464.866	5.24088
21	8.21392	23.4155	4859.06	457.151	5.37469
22	8.64227	23.6156	4645.93	446.259	5.48664
23	9.07062	23.818	4429.07	432.426	5.57632
24	9.49897	24.0228	4209.08	415.921	5.64337
25	9.92732	24.2299	3986.63	397.042	5.68753
26	10.3557	24.4394	3762.44	376.113	5.70862
27	10.784	24.6513	3537.26	353.477	5.7066
28	11.2124	24.8656	3311.92	329.489	5.68142
29	11.6407	25.0823	3087.27	304.517	5.63322
30	12.0691	25.3014	2864.19	278.927	5.56217
31	12.4974	25.523	2643.58	253.084	5.46856
32	12.9258	25.7471	2426.36	227.339	5.35273
33	13.3541	25.9737	2213.44	202.028	5.21513
34	13.7825	26.2027	2005.74	177.466	5.05631
35	14.2108	26.4343	1804.14	153.936	4.87688
36	14.6392	26.6685	1609.52	131.691	4.67752
37	15.0675	26.9052	1422.72	110.947	4.45903
38	15.4959	27.1444	1244.51	91.8786	4.22232
39	15.9242	27.3863	1075.65	74.6185	3.96829
40	16.3526	27.6309	916.835	59.2556	3.69792
41	16.7809	27.878	768.686	45.8346	3.41235
42	17.2093	28.1278	631.776	34.3562	3.1127
43	17.6376	28.3803	506.608	24.7791	2.80021
44	18.066	28.6356	393.622	17.0217	2.47614
45	18.4943	28.8935	293.195	10.9652	2.14181
46	18.9227	29.1542	205.641	6.45754	1.79861
47	19.351	29.4177	131.219	3.31679	1.44794
48	19.7794	29.684	70.1366	1.33599	1.09126
49	20.2077	29.9532	22.5581	0.287441	0.730038
50	20.6361	30.2251	-11.3866	-0.0726938	0.36578
51	21.0644	30.5	0	0	0

## Discharge Sections

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### Entity Information

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◆ [LDCC](#)

**Shared Entities**

Type	Coordinates (x,y)
External Boundary	-0.024, 0 50, 0 50, 17.838 50, 26.0602 50, 29.0745 50, 30.5 47.0919, 30.5 40.4768, 30.5 35.9679, 30.5 30.69, 30.5 26, 30.5 25.4622, 30.5 20.7157, 30.5 15.6382, 30.5 10, 30.5 0, 30.5 -0.00012063, 20
Material Boundary	-0.00012063, 20 5, 20 10, 20 15, 20 18.2711, 20 20, 20 26, 20 38.1735, 26.0602 44.2284, 29.0745 47.0919, 30.5
Material Boundary	18.2711, 20 19.809, 17.838 50, 17.838
Material Boundary	38.1735, 26.0602 50, 26.0602
Material Boundary	44.2284, 29.0745 50, 29.0745
Material Boundary	26, 20 26, 23.0766 26, 25.5084 26, 26.0602 26, 28.1199 26, 30.5

Material Boundary	10, 20 10, 22.5657 10, 25.0686 10, 26.7143 10, 30.5
Material Boundary	10, 20 21.9415, 26.0602 26, 28.1199 27.881, 29.0745 30.69, 30.5
Material Boundary	27.881, 29.0745 33.1212, 29.0745 37.6968, 29.0745 44.2284, 29.0745
Material Boundary	21.9415, 26.0602 26, 26.0602 27.1019, 26.0602 31.8185, 26.0602 38.1735, 26.0602
Material Boundary	-0.00012063, 20 10, 25.0686 20.7157, 30.5
Material Boundary	20, 20 26, 23.0766 31.8185, 26.0602 37.6968, 29.0745 40.4768, 30.5
Material Boundary	5, 20 10, 22.5657 25.4622, 30.5
Material Boundary	15, 20 26, 25.5084 27.1019, 26.0602 33.1212, 29.0745 35.9679, 30.5
Material Boundary	-0.00012063, 20 10, 26.7143 15.6382, 30.5

**CALCULATION VERIFICATION SUBMITTAL**  
**Static Lateral Earth Pressures (Passive Log Spiral)**

**Puyallup River Bridge Replacement  
Calculation Verification Submittal**

**Log Spiral Passive - Abutments.xls**

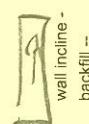
## Appendix A

### Section 6 - LEP for Passive Conditions (Log-spiral) CVS

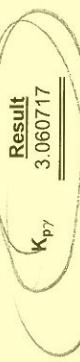
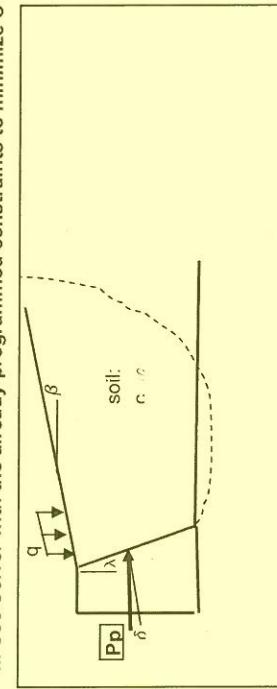
#### Calculation of passive earth pressure coefficient $K_{p\gamma}$ using the log-spiral slip surface

\*From Soubra and Macuh (2002) "Active and Passive EP Coeff by a Kinematical Approach" Geotechnical Engr 155(2) 119-131.

Input Data		(°)	(rad)
$\phi$	24	0.418879	
$\delta$	10	0.174533	
$\lambda$	0	0	
$\beta$	0	0	
Unknowns		(°)	(rad)
$\theta_0$	0.712605	40.82924	
$\theta_1$	1.149408	65.8562	



!!! Use Solver with the already-programmed constraints to minimize C19 !!!



$K_{p\gamma}$   
3.060717

$$P_p = \frac{1}{2} K_{p\gamma} \gamma l^2 + K_{pq} q l + K_{pc} c l$$

$$\text{where } l = \text{wall length} = \frac{H}{\cos \lambda}$$

$\lambda$	0	degrees
H	16.75	ft
I	16.8	ft
$\gamma$ -soil	20	pcf
cohesion	0	psf
surcharge	0	psf



$K_{p\gamma}$   
3.060717  
 $K_{pc}$   
 $K_{pq}$

3.060717	<----- If you have no surcharge or cohesion, this is your $K_p$

$P_p =$  8456.764 lb/ft

Horiz.  $P_p =$  8.46 kips/lineal foot of wall

- Instructions for use:
1. Input your data (only change the numbers in blue!!)
  2. Go to cell C19 and change the function to whichever K you are interested in obtaining ( $K_p = K_{pg}$ , etc.) Make sure you leave the cell selected. Also, just change the 'K.' part - don't change the cell references.
  3. Go to 'Tools', then 'Solver\*', then click 'Solve'. ....the constraints should already be entered. If the constraints are not entered, refer to the handout to re-enter them.
  4. Once you have your K's, plug into equation shown to the left to obtain the total passive force  $P_p$ .

\* If 'Solver' does not appear in the tools menu, go to 'Add-ins' and add it to your tools. Also, you may find it more convenient to hot-key 'solver' ....Alt-t then v then Enter'

The different commands for the K functions are:  
 $K_{pg}$  ( .....for  $K_p$ \_gamma  
 $K_{pc}$  ( .....for  $K_p$ \_cohesion  
 $K_{pq}$  ( .....for  $K_p$ \_surcharge


**HARTCROWSER**

Delivering smarter solutions

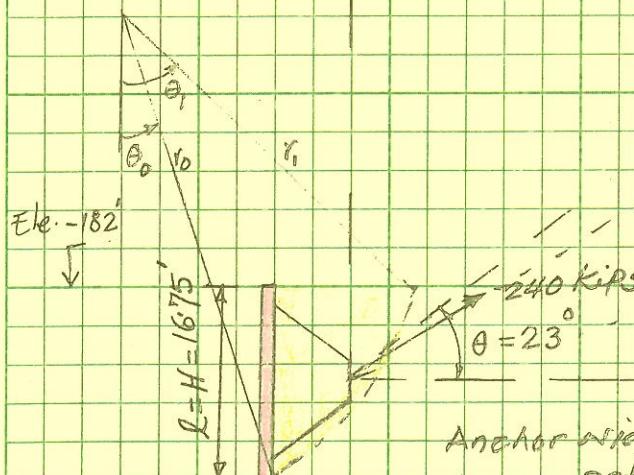
Project \_\_\_\_\_

Calculations for Passive pressure by Rotational Log spiral Failure Mechanism**Calculations**Page 1 of 14

Job No. \_\_\_\_\_

Made By MSK Date Sep 13, 2011

Checked By \_\_\_\_\_ Date \_\_\_\_\_

Lake Water  $\nabla$  Ele. 20.6 feet

$$\text{Anchor width} = 33 \text{ ft}$$

$$\gamma = 20 \text{ pcf}$$

$$\phi = 24$$

$$K_a = \tan^2(45 - \frac{\phi}{2}) = 0.42$$

$$P_a = \frac{1}{2} \times 20 \times (0.42) \times (16.75)^2 \times 33 / 1000 \\ = 39 \text{ kips}$$

$$\text{Total horizontal load} = 39 + 240 \cos(23^\circ) \\ = 260 \text{ kips}$$

$$\text{Target } P_p = \frac{260}{33} = 7.9 \text{ kips/ft.}$$

$$\text{Active earth pressure coefficient, } K_a = \tan^2(45 - \frac{\phi}{2}) \\ = 0.42$$

**HARTCROWSER**

Delivering smarter solutions

Project \_\_\_\_\_

Calculations for \_\_\_\_\_

**Calculations**Page 2 of 4

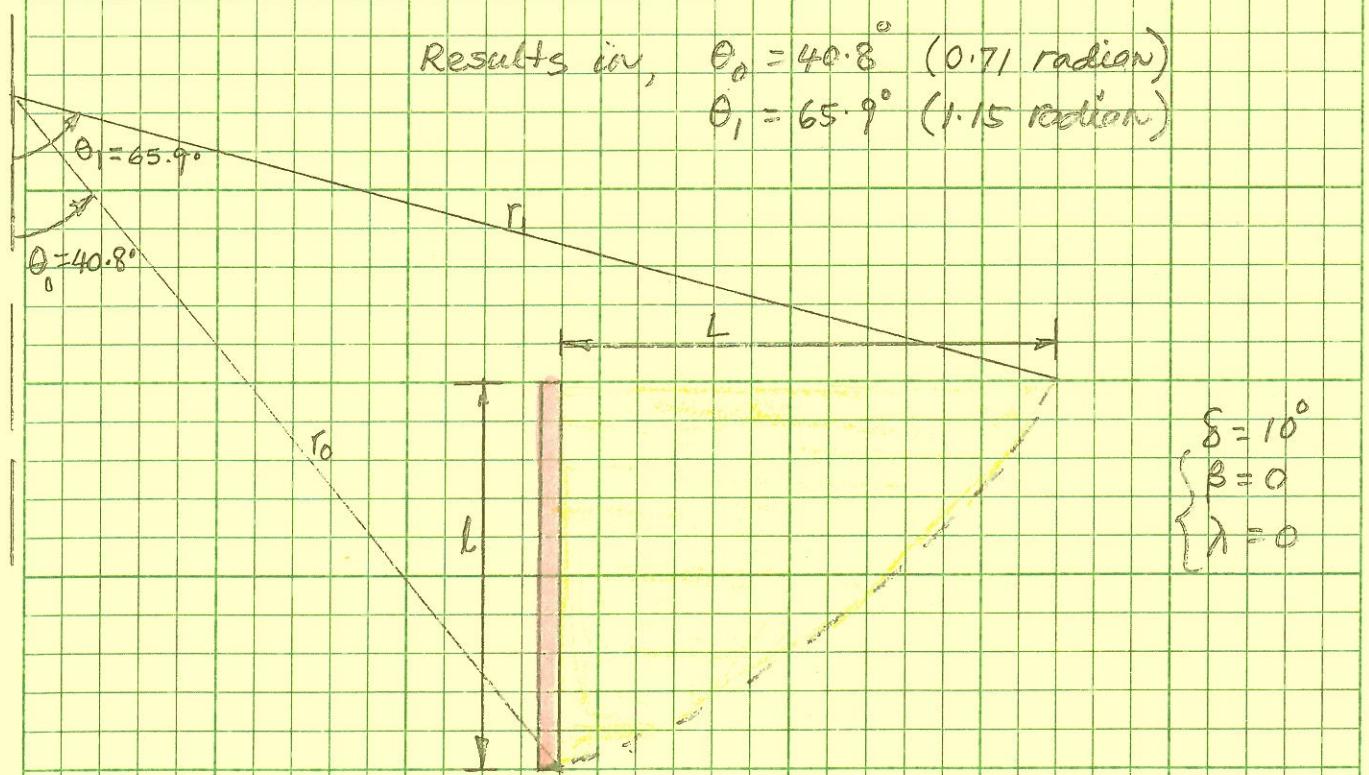
Job No. \_\_\_\_\_

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Excel solver: Minimizing  $K_{PV}$  (Cell - C19) subject to:

$$\left\{ \begin{array}{l} \theta_0 \leq 3.14 \text{ radian} \\ \theta_1 \leq 3.14 \text{ radian} \\ \theta_1 \geq \theta_0 + 0.0001 \\ \theta_1 \geq 0 \\ K_{PV} \geq 0 \end{array} \right.$$

Results are,  $\theta_0 = 40.8^\circ$  (0.71 radian) $\theta_1 = 65.9^\circ$  (1.15 radian)

$$\begin{aligned}
 f_1 &= -\frac{e^{3(\theta_1 - \theta_0)\tan\phi}(3\tan\phi \cdot \sin\theta_1 - \cos\theta_1) - 3\tan\phi \cdot \sin\theta_0 + \cos^3\theta_0}{3(9\tan^2\phi + 1)} \\
 &= -\frac{e^{0.59}(1.22 - 0.41) - 0.87 + 0.76}{3(1.28)} \\
 &= -\frac{1.80 \times 0.81 - 0.11}{8.35} \\
 &= -0.16
 \end{aligned}$$


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$$\frac{L}{r_0} = \frac{e^{(\theta_1 - \theta_0) \tan \delta} (\sin \theta_1 - \cos \theta_1 \tan \lambda) - \sin \theta_0 + \cos \theta_0 \cdot \tan \lambda}{\sin \beta \cdot \tan \lambda + \cos \beta}$$

$$= \frac{e^{0.20} (0.91 - 0) - 0.65 + 0}{0 + 1}$$

$$= 0.46$$

$$\frac{L}{r_0} = - \frac{e^{(\theta_1 - \theta_0) \tan \phi} \cdot \cos(\theta_1 - \beta) + \cos(\theta_0 - \beta)}{\cos(\beta - \lambda)}$$

$$= - \frac{e^{0.2} \cdot 0.41 + 0.76}{1}$$

$$= + 0.26$$

$$f_2 = -\frac{1}{6} \frac{L}{r_0} \left( 2 \sin \theta_0 - 2 \frac{L}{r_0} \sin \lambda + \frac{L}{r_0} \cos \beta \right) \cdot \cos(\theta_1 - \beta) e^{(\theta_1 - \theta_0) \tan \delta}$$

$$= -\frac{1}{6} (0.41) (1.31 - 0 + 0.46) 0.41 \cdot e^{0.20}$$

$$= -0.066$$

$$f_3 = -\frac{1}{6} \frac{L}{r_0} \sin(\theta_0 - \lambda) \left( 2 \sin \theta_0 - \frac{L}{r_0} \sin \lambda \right)$$

$$= -\frac{1}{6} (0.26) (0.65) (1.31 - 0)$$

$$= -0.037$$

$$f_4 = \cos(\delta - \lambda) \left( \cos \theta_0 - \frac{1}{3} \frac{L}{r_0} \cos \lambda \right) - \sin(\delta - \lambda) \left( \sin \theta_0 - \frac{1}{3} \frac{L}{r_0} \sin \lambda \right)$$

$$= 0.98 [0.76 - \frac{1}{3} (0.26)] - 0.17 (0.65 - 0)$$

$$= 0.55$$


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$$\begin{aligned}
 K_{PY} &= -\frac{2}{\left(\frac{L}{B}\right)^2} \frac{(f_1 - f_2 - f_3)}{f_1} \\
 &= -\frac{2}{(0.26)^2} \frac{[-0.16 - (-0.066) - (-0.037)]}{0.55} \\
 &= -29.59 \left[ \frac{-0.16 + 0.103}{0.55} \right] \\
 &\approx 3.06
 \end{aligned}$$

Calculated  $P_p = \frac{1}{2} K_{PY} Y L^2 \cos \delta$  [Horizontal Component]

$$\begin{aligned}
 &= [(0.5) \cdot (3.06) \cdot (20) \cdot (16.75)^2 / 1000] \cos 10 \\
 &= 8.6 \times (0.98) \\
 &\approx 8.4 \text{ kips/ft} \quad (\text{Target } P_p = 7.9 \text{ kips/ft})
 \end{aligned}$$

**CALCULATION VERIFICATION SUBMITTAL**  
**Seismic Lateral Earth Pressures**

**Mononobe-Okabe Method (M-O)**

Pseudo-static analysis of seismic earth pressure on retaining structures

Job Name: job name  
Job Number: J ##### ##**NOTES:**

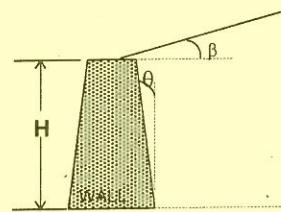
- (1) Refer to Geotechnical Earthquake Engineering by Kramer before using
- (2) Refer to Sections 11.5 & 11.6, 11.8.1.1, and Figure 11.11 a (Kramer)
- Note: 1/3 to 1/2 peak ground surface accelerations are typically used in M-O equation (see Kramer Sect. 11.8.1.1, p. 494)  
kv can be assumed =0 when using M-O method for typ. wall designs (Seed and Whitman ,1970; see Kramer p. 479)
- (3) This method does not include a water table.
- (4) This method is only recommended as a rough estimate for tiebacks.
- (5) Check with hand calculations.
- (6) Insert values into yellow areas.
- (7) This method assumes a "Yielding" wall condition
- (8) Paper: "Seismic Design and Behavior of Gravity Retaining Walls" by Robt. V. Whitman

Parameters	Symbol	Value	Units
Slope Inclination	$\beta$	0.000	radians
Horizontal Acceleration coef/g	$k_h$	0.15	
Vertical Acceleration coef/g	$k_v$	0.075	
Soil Friction Angle	$\phi$	0.593	radians
Soil/Wall Friction Angle	$\delta$	0.297	radians
Wall Angle (Batter) from Vertical	$\theta$	0.000	radians
Unit Weight	$\gamma$	110	pcf
Height of Wall	H	20	feet

Conversion from degrees to radians:

Degrees	Radians	Reference	
0	0.0000	Slope	$\beta$
		1.5H:1V	33.7
		1.75H:1V	29.7
34	0.5934	2H:1V	26.6
17	0.2967	2.5H:1V	21.8
0	0.0000	3H:1V	18.4
		3.5H:1V	15.9
		4H:1V	14.0
		5H:1V	11.3
		10H:1V	5.7

To be calculated	Symbol	Value
Coeff. of Active Earth Pressure	$K_a$	calculated
Active earth pressure resultant	$P_a$	calculated
Total Lateral Force	$P_{ae}$	calculated
Dynamic Active Earth Pressure	$K_{ae}$	calculated
Total thrust acts at this height:	h	calculated
Critical Failure Surface from Horz.	$\alpha_{ea}$	calculated

**Active Earth Pressure Calculations**

Active Earth Pressure Coefficient	$K_a$	=	0.256
Active thrust static component	$P_a$	=	5642 pounds/foot
$\text{ArcTan}(kh/(1-kv)) =$	$\psi$	=	0.1608 radians = 9.2 degrees
Dynamic active earth press. coef.	$K_{ae}$	=	0.362
Total Active Thrust	$P_{ae}$	=	7374 pounds/foot
Active thrust dynamic component	$\Delta P_{ae}$	=	1732 pounds/foot
Total Active Thrust acts at:	h	=	7.9. feet
Overspin moment about base	$M_o$	=	55844 ft-lb/ft

Static Equivalent Active Fluid Unit Weight = 28 pcf

9.2 degrees

Dynamic Equivalent Active Fluid Unit Weight = 40 pcf

Dynamic Uniform Lateral Surcharge = 87 psf or = 4.3H

Note: The dynamic portion of the equivalent fluid unit weight is typically applied as a rectangular distribution rather than a triangular distribution.

The above calculations correspond to a critical failure surface angle of	$\alpha_{EA}$	=	0.887 radians = 51 degrees above horizontal
--	---------------	---	---

Static conditions produce a critical failure surface angle of	$\alpha_s$	=	1.082 radians = 62 degrees above horizontal
---	------------	---	---

**Passive Earth Pressure Calculations**

Passive Earth Pressure Coefficient $K_p$	=	6.767422 (Coulomb)
Passive thrust static component $P_p$	=	148883 pounds/foot
Dynamic passive earth press. coef $K_{pe}$	=	5.89
Total Passive Thrust $P_{pe}$	=	119953 pounds/foot
Passive thrust dynamic component $\Delta P_{pe}$	=	-28931 pounds/foot

Static Equivalent Passive Fluid Unit Weight = 744 pcf

Dynamic Equivalent Passive Fluid Unit Weight = 648 pcf

The above calculations correspond to a critical failure surface angle of	$\alpha_{pe}$	=	0.40 radians = 23 degrees above horizontal
--	---------------	---	--

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Calculations for Seismic Earth Pressures on Retaining Structures

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Basis of design Calculations

The following pages summarize the calculations made in the excel spreadsheet titled Mononobe-Okabe Method v2.91.xls.

The calculations follow the procedures outlined by the "Mononobe-Okabe Method" described by Kramer (1996).

An Example calculation along with the original spreadsheet are presented for comparison.

Conclusions

Example Calculations provide the same results as presented in the spreadsheet, showing that the above mentioned spreadsheet provides accurate calculations according to Kramer (1996).

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Calculations for Seismic Earth Pressures on Retaining Structures

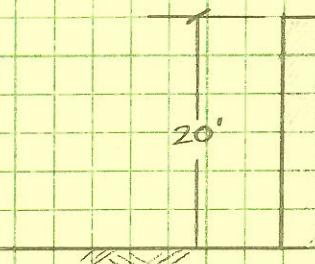
Calculations

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Example Calculation: $\gamma = 110 \text{pcf}$  Unit weight of soil $\phi = 34^\circ$  Friction angle $\delta = 17^\circ$  Soil/Wall friction angle $\beta = 0^\circ$  Slope Inclination $\Theta = 0^\circ$  Wall angle from Vertical $k_h = 0.15$  Horizontal acceleration Coeff. $k_v = 0.075$  Vertical acceleration Coeff.Mononobe-Okabe Method: (active)

$$\Psi = \tan^{-1} \left( \frac{k_h}{1 + k_v} \right) = \tan^{-1} \left( \frac{0.15}{1 + 0.075} \right) = 0.161 \text{ rad or } 9.21^\circ \text{ OK}$$

$$K_{AE} = \frac{\cos^2(\phi - \theta - \Psi)}{\cos \Psi \cos^2 \theta \cos(\delta + \theta + \Psi) \left[ 1 + \sqrt{\frac{\sin(\delta + \phi) \sin(\phi - \beta - \Psi)}{\cos(\delta + \theta + \Psi) \cos(\beta - \theta)}} \right]^2}$$

Where:  $K_{AE}$  = dynamic active earth pressure coefficient

$$K_{AE} = \frac{\cos^2(34^\circ - 0 - 9.21^\circ)}{\cos(9.21^\circ) \cos^2(0) \cos(17^\circ + 0 + 9.21^\circ) \left[ 1 + \sqrt{\frac{\sin(17^\circ + 34^\circ) \sin(34^\circ - 0 - 9.21^\circ)}{\cos(17^\circ + 0 + 9.21^\circ) \cos(0 - 0)}} \right]^2}$$

$$= \frac{0.8242}{(0.9871)(1)(0.8972) \left[ 1 + \sqrt{\frac{(0.7771)(0.4193)}{(0.8972)(1)}} \right]^2} = \frac{0.8242}{(0.8856)(2.5685)}$$

$$\Rightarrow K_{AE} = \underline{0.362 \text{ OK}}$$

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$$P_{AE} = \frac{1}{2} K_{AE} \gamma H^2 (1 - k_A)$$

$$= \frac{1}{2} (0.362) (110 \text{pcf}) (20 \text{ft})^2 (1 - 0.075)$$

$$= \underline{\underline{7,374 \text{ lb/ft}}} \quad \underline{\text{OK}}$$

Where:  $P_{AE}$  = Total active dynamic thrust per foot of wall

The total active thrust acts at height 'h' above foot of the wall. This requires knowledge of the static active thrust force on the wall.

$$K_A = \frac{\cos^2(\phi - \theta)}{\cos^2 \theta \cos(\delta + \theta) \left[ 1 + \sqrt{\frac{\sin(\delta + \theta) \sin(\phi - \theta)}{\cos(\delta + \theta) \cos(\phi - \theta)}} \right]^2}$$

$$= \frac{\cos^2(34 - 0)}{\cos^2(0) \cos(17^\circ + 0) \left[ 1 + \sqrt{\frac{\sin(17^\circ + 34^\circ) \sin(34 - 0)}{\cos(17^\circ + 0) \cos(0 - 0)}} \right]^2} = \frac{0.687}{(0.956)(2.803)}$$

$$\rightarrow K_A = \underline{\underline{0.256}} \quad \underline{\text{OK}}$$

$$P_A = \frac{1}{2} K_A \gamma H^2$$

$$= \frac{1}{2} (0.256) (110 \text{pcf}) (20')^2 = \underline{\underline{5642 \text{ lb/ft}}} \quad \underline{\text{OK}}$$

Where:  $K_A$  = Static active earth pressure coefficient

$P_A$  = Total active thrust per foot of wall

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Calculations

Page 4 of 9Job No. 1763801Made By JCV Date 4/6/11 $\Delta P_{AE}$  = Dynamic Component of  $P_{AE}$ 

$$= P_{AE} - P_A = 7,374 \text{ lb/ft} - 5,642 \text{ lb/ft}$$

$$= \underline{1732 \text{ lb/ft}} \quad \underline{\text{OK}}$$

$$h = \frac{P_A H/3 + \Delta P_{AE} (0.6 H)}{P_{AE}}$$

$$= \frac{(5642 \text{ lb/ft})(20')/3 + (1732 \text{ lb/ft})(0.6)(20')}{7374 \text{ lb/ft}} = \frac{58396 \text{ lb}}{7374 \text{ lb/ft}}$$

$$\rightarrow h = \underline{7.9 \text{ ft}} \quad \underline{\text{OK}}$$

$\alpha_{AE}$  = Critical Failure Surface, Passive  
 $C_{IE}, C_{ZE}$  = Values used to calculate  $\alpha_{AE}$

$$\begin{aligned} C_{IE} &= \sqrt{\tan(\phi + \psi - \beta)[\tan(\phi + \psi - \beta) + \cot(\phi - \psi - \theta)][1 + \tan(\delta + \psi + \theta)\cot(\phi - \psi - \theta)]} \\ &= \sqrt{\tan(34^\circ - 9.21^\circ - 0)[\tan(34^\circ - 9.21^\circ - 0) + \cot(34^\circ - 9.21^\circ - 0)][1 + \tan(17^\circ - 9.21^\circ + 0)\cot(34^\circ - 9.21^\circ)]} \\ &= \sqrt{0.4618(0.4618 + 2.1653)[1 + (0.4923)(2.1653)]} \\ &= \underline{1.58} \end{aligned}$$

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Project SR99 Tunnel

Calculations for Seismic Earth Pressures on Retaining Structures

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$$C_{2E} = 1 + \{ \tan(\delta + \psi + \theta) [\tan(\phi - \psi - \beta) + \cot(\phi - \psi - \theta)] \}$$

$$= 1 + \{ \tan(17^\circ + 9.21^\circ + 0) [\tan(34^\circ - 9.21^\circ - 0) + \cot(34^\circ - 9.21^\circ - 0)] \}$$

$$= 1 + [0.4923 (0.4618 + 2.16529)]$$

$$= 2.29$$

$$\alpha_{AE} = \phi - \psi + \tan^{-1} \left[ \frac{-\tan(\phi - \psi - \beta) + C_{1E}}{C_{2E}} \right]$$

$$= 34^\circ - 9.21^\circ + \tan^{-1} \left[ \frac{-\tan(34^\circ - 9.21^\circ - 0) + 1.5832}{2.2933} \right]$$

$$= 51^\circ \text{ above horizontal}$$

$M_o$  = Overturning moment about base

$$M_o = P_{AE} h \cos(\theta + \delta)$$

$$= (7374 \text{ lb/ft})(7.9') \cos(0 + 17^\circ)$$

$$= 55844 \text{ ft-lb/ft of wall} \quad \underline{\text{OK}}$$

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Monobe - Okabe : (Passive)

The following equations calculate the total passive thrust  
on the same wall on page 2.

 $K_p = \text{coefficient of passive lateral Earth pressure, static (Coulomb)}$ 
 $P_p = \text{Static Passive Thrust}$ 

$$K_p = \frac{\cos^2(\phi + \theta)}{\cos^2\theta \cos(\delta - \theta) \left[ 1 - \sqrt{\frac{\sin(\delta + \phi) \sin(\phi + \beta)}{\cos(\delta - \theta) \cos(\beta - \theta)}} \right]^2}$$

$$= \frac{\cos^2(34^\circ + 0)}{\cos^2(0) \cos(17^\circ - 0) \left[ 1 - \sqrt{\frac{\sin(17^\circ + 34^\circ) \sin(34^\circ + 0)}{\cos(17^\circ - 0) \cos(0 - 0)}} \right]^2}$$

$$= \frac{0.6873}{(0.9563)(0.1062)} = \underline{\underline{6.7674}} \quad \underline{\underline{OK}}$$

$$P_p = \frac{1}{2} K_p H^2 = \frac{1}{2} (6.7674) (110 \text{pcf}) (20')^2$$

$$= \underline{\underline{148,883 \text{ lb/ft}}} \quad \underline{\underline{OK}}$$

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 $K_{PE}$  = dynamic passive earth pressure coefficient $P_{PE}$  = Total passive thrust on wall $\Delta P_{PE}$  = Dynamic Passive Thrust Component

$$K_{PE} = \frac{\cos^2(\phi + \theta - \psi)}{\cos \psi \cos^2 \theta \cos(\delta - \theta - \psi) \left[ 1 - \sqrt{\frac{\sin(\delta + \phi) \sin(\phi + \beta - \psi)}{\cos(\delta - \theta + \psi) \cos(\beta - \theta)}} \right]^2}$$

$$= \frac{\cos^2(34^\circ + 0 - 9.21^\circ)}{\cos(9.21^\circ) \cos^2(0) \cos(17^\circ - 0 + 9.21^\circ) \left[ 1 - \sqrt{\frac{\sin(17^\circ + 34^\circ) \sin(34^\circ + 0 - 9.21^\circ)}{\cos(17^\circ - 0 + 9.21^\circ) \cos(0 - 0)}} \right]^2}$$

$$= \frac{0.8242}{(0.8856)(0.1579)} = \underline{5.89} \quad \underline{OK}$$

$$P_{PE} = \frac{1}{2} K_{PE} \gamma H^2 (1 - k_v)$$

$$= \frac{1}{2} (5.8945) (110 \text{pcf}) (20')^2 (1 - 0.075)$$

$$= \underline{119,953 \text{ lb/ft}} \quad \underline{OK}$$

$$\Delta P_{PE} = P_{PE} - P_p = 119,953 \text{ lb/ft} - 148,883 \text{ lb/ft}$$

$$= \underline{-28,931 \text{ lb/ft}} \quad \underline{OK}$$


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 $\alpha_{pe}$  = Critical failure Surface angle $C_{3E}, C_{4E}$  = Values used to calculate  $\alpha_{pe}$ 

$$C_{3E} = \frac{\sqrt{\tan(\phi + \beta - \psi)[\tan(\phi + \beta - \psi) + \cot(\phi + \theta - \psi)]}}{[1 + \tan(\delta + \psi - \theta)\cot(\phi + \theta - \psi)]}$$

$$= \frac{\sqrt{\tan(34^\circ + 0 - 9.21^\circ)[\tan(34^\circ + 0 - 9.21^\circ) + \cot(34^\circ + 0 - 9.21^\circ)]}}{[1 + \tan(17^\circ + 9.21^\circ - 0)\cot(34^\circ + 0 - 9.21^\circ)]}$$

$$= \sqrt{(0.4618)(0.4618 + 2.1653)} [1 + (0.4923)(2.1653)]$$

$$= 1.58 \quad \underline{\text{OK}}$$

$$C_{4E} = 1 + \{\tan(\delta + \psi - \theta)[\tan(\phi + \beta - \psi) + \cot(\phi + \theta - \psi)]\}$$

$$= 1 + \{\tan(17^\circ + 9.21^\circ - 0)[\tan(34^\circ + 0 - 9.21^\circ) + \cot(34^\circ + 0 - 9.21^\circ)]\}$$

$$= 1 + (0.4923)(0.4618 + 2.1653)$$

$$= 2.29 \quad \underline{\text{OK}}$$

$$\alpha_{pe} = \psi - \phi + \tan^{-1} \left[ \frac{\tan(\phi + \psi + \beta) + C_{3E}}{C_{4E}} \right] = 9.21^\circ + 34^\circ$$

$$+ \tan^{-1} \left[ \frac{\tan(34^\circ + 9.21^\circ + 0) + 1.58}{2.29} \right]$$

$$= 23^\circ \text{ above Horizontal} \quad \underline{\text{OK}}$$

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$$\text{Static Equivalent Active Fluid Unit Weight} = K_a \gamma$$

$$= (0.256)(110 \text{ pcf})$$

$$= \underline{\underline{28 \text{ pcf}}}$$

$$\text{Dynamic Equivalent Active Fluid Unit Weight} = K_{AE} \gamma$$

$$= (0.362)(110 \text{ pcf})$$

$$= \underline{\underline{40 \text{ pcf}}}$$

$$\text{Dynamic Uniform Lateral Surcharge} = \Delta P_{AE} / H$$

$$= 1732 \text{ lb/ft} / 20 \text{ ft.}$$

$$= \underline{\underline{.87 \text{ psf}}}$$

$$\text{Dynamic Uniform Lateral Surcharge per foot of wall}$$

$$= \Delta P_{AE} / H^2 \times H$$

$$= 1732 \text{ lb/ft} / (20 \text{ ft})^2 \times H$$

$$= \underline{\underline{4.3 H}}$$

$$\text{Static Equivalent Passive Fluid Unit Weight} = K_p \gamma$$

$$= (6.767)(110 \text{ pcf})$$

$$= \underline{\underline{744 \text{ pcf}}}$$

$$\text{Dynamic Equivalent Passive Fluid Unit Weight} = K_{PE} \gamma$$

$$= (5.89)(110 \text{ pcf})$$

$$= \underline{\underline{648 \text{ pcf}}}$$

**CALCULATION VERIFICATION SUBMITTAL**  
**LDCC Sliding Resistance - Minimum Required Width**

## Appendix A

### Section 8 - LDCC Sliding Resistance - Min Width CVS

Minimum width of LDCC required for sliding resistance to overcome seismic active earth pressures behind the LDCC mass

Input Cell

Calculation Cell

#### LDCC Parameters

LDCC Unit Weight, pcf	35
LDCC Height, ft	10.5

Example Calculation

#### Sliding Resistance of LDCC for Different Bearing Layers

Bearing Soil	Friction Angle (deg)	Cohesion (psf)	Sliding Resistance (psf) <sup>a</sup>
ESU 3B	34	0	247.88
ESU 4D	35	700	957.33

Notes:

a. Lower sliding resistance between ESU 3B and ESU 4D bearing layer used to calculate minimum required width of LDCC.

Example Calculation

#### Minimum LDCC Width for Varying LDCC Batter Angles, Flat Backslope

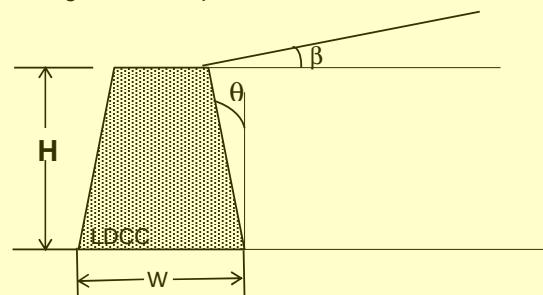
LDCC Width (ft)	LDCC Sliding Resistance Bearing on ESU 3B (lb/ft)	LDCC Backslope from Vertical, $\theta$ (deg)*	LDCC Backslope from Horizontal (deg)	LDCC Backslope (H:V)
4	992	-48	42	1.11
5	1239	-42	48	0.90
7.5	1859	-27	63	0.51
10	2479	-13	77	0.23
13	3222	0	90	0.00

Notes:

a. Backslopes correspond to the seismic active earth pressure of ESU 3B equal to the LDCC sliding resistance for the selected width.

b. See seismic active earth pressure calculation for each backslope angle in Mononobe-Okabe LEP calculation spreadsheets.

c. Sliding calculated per AASHTO LRFD Section 10.6.3.4.



PROJECT: I-405 Renton to Belleue Express Toll Lanes JOB NO: 19434-04

SUBJECT: Bridge 28E LDCC Minimum Required Width - Calculation Verification Submittal

CREATED BY: AMH DATE: 08/11/2021

CHECKED BY: JRJ DATE: 08/11/2021

### Basis of Calculations

The following calculation verification submittal (CVS) presents the estimated minimum required width (measured from the back of the pile cap) of the low density cellular concrete (LDCC) required for sliding resistance to overcome lateral loading of the retained soil. The sliding resistance of the LDCC fill was calculated per the methods outlined in *AASHTO LRFD Bridge Design Specifications* Section 10.6.3.4. The seismic active lateral earth pressure of the retained soil (ESU 3B) was used as the lateral loading on the LDCC mass.

The following summarizes lateral inertial load calculations made in the excel spreadsheet "Mononobe-Okabe\_DM7.2\_LDCC\_8.4.21.xlsx".

An example calculation along with the spreadsheet are presented for comparison.

### Conclusions

Example calculations show the same results as provided in the spreadsheet, showing that the above mentioned spreadsheet provides accurate calculations.

### Basis of Sliding Shear Calculation from *AASHTO LRFD Bridge Design Specifications* Section 10.6.3.4.

#### 10.6.3.4—Failure by Sliding

Failure by sliding shall be investigated for footings that support horizontal or inclined load and/or found on slopes.

For foundations on clay soils, the possible presence of a shrinkage gap between the soil and the foundation shall be considered. If passive resistance is included as part of the shear resistance required for resisting sliding, consideration shall also be given to possible future removal of the soil in front of the foundation.

The factored resistance against failure by sliding, in kips, shall be taken as:

$$R_R = \varphi R_n = \varphi_t R_t + \varphi_{ep} R_{ep} \quad (10.6.3.4-1)$$

where:

$R_n$  = nominal sliding resistance against failure by sliding (kips)

$\varphi_t$  = resistance factor for shear resistance between soil and foundation specified in Table 10.5.5.2.2-1

$R_t$  = nominal sliding resistance between soil and foundation (kips)

$\varphi_{ep}$  = resistance factor for passive resistance specified in Table 10.5.5.2.2-1

$R_{ep}$  = nominal passive resistance of soil available throughout the design life of the structure (kips)

If the soil beneath the footing is cohesionless, the nominal sliding resistance between soil and foundation shall be taken as:

$$R_t = CV \tan \phi_f \quad (10.6.3.4-2)$$

for which:

$C$  = 1.0 for concrete cast against soil  
= 0.8 for precast concrete footing

where:

$\phi_f$  = internal friction angle of drained soil (degrees)

$V$  = total vertical force (kips)

#### C10.6.3.4

Sliding failure occurs if the force effects due to the horizontal component of loads exceed the more critical of either the factored shear resistance of the soils or the factored shear resistance at the interface between the soil and the foundation.

For footings on cohesionless soils, sliding resistance depends on the roughness of the interface between the foundation and the soil.

The magnitudes of active earth load and passive resistance depend on the type of backfill material, the wall movement, and the compactive effort. Their magnitude can be estimated using procedures described in Sections 3 and 11.

In most cases, the movement of the structure and its foundation will be small. Consequently, if passive resistance is included in the resistance, its magnitude is commonly taken as 50 percent of the maximum passive resistance. This is the basis for the resistance factor,  $\varphi_{ep}$ , in Table 10.5.5.2.2-1.

The units for  $R_n$ ,  $R_t$ , and  $R_{ep}$  are shown in kips. For elements designed on a unit length basis, these quantities will have the units of kips per unit length.

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#### AASHTO LRFD BRIDGE DESIGN SPECIFICATIONS, EIGHTH EDITION, 2017

correlation to in-situ measured SPT or cone resistance values, or measured  $\tan \delta$  from laboratory testing, experience has shown that Table C3.11.5.3-1 may be used to estimate the coefficient of friction  $\tan \delta$  between soil and various footing material types in Eq. 10.6.3.4-2.

For footings that rest on clay, where footings are supported on at least 6.0 in. of compacted granular material, the sliding resistance may be taken as the lesser of:

- the cohesion of the clay, or
- one-half the normal stress on the interface between the footing and soil, as shown in Figure 10.6.3.4-1 for retaining walls.

The following notation shall be taken to apply to Figure 10.6.3.4-1:

$q_s$  = unit shear resistance, equal to  $S_u$  or 0.5  $\sigma'$ , whichever is less

$R_t$  = nominal sliding resistance between soil and foundation (kips) expressed as the shaded area under the  $q_s$  diagram

$S_u$  = undrained shear strength (ksf)

$\sigma'_v$  = vertical effective stress (ksf)

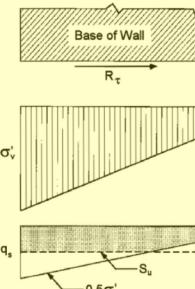


Figure 10.6.3.4-1—Procedure for Estimating Nominal Sliding Resistance for Walls on Clay

Example calculation for rows 13 and 21

Inputs

LDCC Height (ft) - West Abutment.....	$H := 10.5 \text{ ft}$
LDCC Dry Density.....	$\gamma_{LDCC} := 35 \text{ pcf}$
Potential Bearing Soil - ESU 3B Friction Angle.....	$\phi_{ESU3B} := 34 \text{ deg}$
Potential Bearing Soil - ESU 3B Cohesion.....	$C'_{ESU3B} := 0 \text{ psf}$
Potential Bearing Soil - ESU 4D Friction Angle.....	$\phi_{ESU4D} := 29 \text{ deg}$
Potential Bearing Soil - ESU 4D Cohesion.....	$C'_{ESU4D} := 700 \text{ psf}$

LDCC Sliding Resistance for Different Bearing Layers

$$\text{Sliding Resistance on ESU 3B} \dots R_{ESU3B} := C'_{ESU3B} + (H \cdot \gamma_{LDCC} \cdot \tan(\phi_{ESU3B})) = 247.9 \text{ psf}$$

$$\text{Sliding Resistance on ESU 4D} \dots R_{ESU3B} := C'_{ESU4D} + (H \cdot \gamma_{LDCC} \cdot \tan(\phi_{ESU4D})) = 903.7 \text{ psf}$$

$$\text{LDCC Width} \dots W := 4 \text{ ft}$$

$$\text{LDCC Sliding Resistance Bearing on ESU 3B} \dots R_{sliding} := (H \cdot \gamma_{LDCC} \cdot \tan(\phi_{ESU3B})) \cdot W = 992 \frac{\text{lbf}}{\text{ft}}$$

$$R_{sliding} = 992 \frac{\text{lbf}}{\text{ft}} \quad \text{OK}$$

**CALCULATION VERIFICATION SUBMITTAL  
Kmax Reduction and Deformation – NCHRP 611**

## Calculation Verification Submittal

### Estimating Wall Seismic Acceleration Considering Wave Scattering and Wall Displacement

The following calculation verification submittal (CVS) presents the estimation of wall seismic acceleration considering wave scattering effects and wall displacement per AASHTO LRFD 8 (2017) – Section A11.5.2 and NCHRP Report 611 (2008). This method modifies the seismic coefficient used to compute the lateral load acting on a freestanding retaining wall to account for the effects of spatially varying ground motions behind the wall.

We have generally followed the method as shown in AASHTO Section A11.5.2, with the exception of equation A11.5.2-3. The third term in this equation is written incorrectly when compared to NCHRP 611. Therefore, the third term has been replaced with the NCHRP 611 version as shown below. All other terms in the equation remain the same.

$$\log d = -1.51 - 0.74 \log \left( \frac{k_v}{k_{h0}} \right) + 3.27 \log \left( \frac{1 - k_y / k_{\max}}{k_{h0}} \right) - 0.80 \log k_{h0} + 1.59 \log(PGV) \quad (\text{A11.5.2-3})$$

## Appendix A

## Section 9 - Kmax Reduction and Deformation CVS

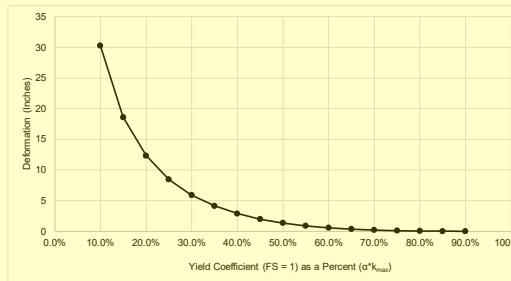
Per NCHRP Report 611

Direct Input  
Calculation Cell  
Output

$k_y$ estimate:	
H (ft)	20
$F_y$	2.034
$S_1$	0.283
$k_{max}$ (PGA)	0.503
$\beta$	1.144
$\alpha$	0.914
$\alpha^* k_{max}$	0.460
$0.5^* \alpha^* k_{max}$	0.230

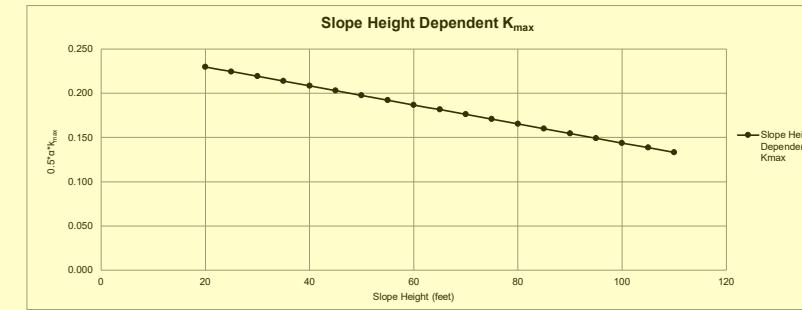
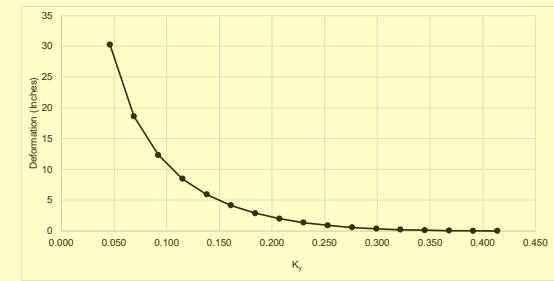
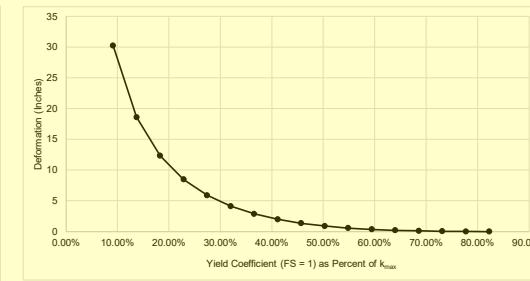
Displacement Estimate for Specified $k_y$ :	
$k_y$ (alternate)	0.23
% of $\alpha^* k_{max}$	50.00%
pgv	21.874
log(d)	0.129
d (inches)	1.344
d (inches)	1.344
% PGA ( $A_s$ )	45.73%

Example 1



$k_y$ for Varying Percentages of $\alpha^* k_{max}$ and Respective Estimated Displacements																	
$k_y$ (alternate)	0.046	0.069	0.092	0.115	0.138	0.161	0.184	0.207	0.230	0.253	0.276	0.299	0.322	0.345	0.368	0.391	0.414
% of $\alpha^* k_{max}$	10.0%	15.0%	20.0%	25.0%	30.0%	35.0%	40.0%	45.0%	50.0%	55.0%	60.0%	65.0%	70.0%	75.0%	80.0%	85.0%	90.0%
pgv	21.874	21.874	21.874	21.874	21.874	21.874	21.874	21.874	21.874	21.874	21.874	21.874	21.874	21.874	21.874	21.874	21.874
log(d)	1.481	1.269	1.091	0.927	0.771	0.616	0.459	0.298	0.129	-0.052	-0.247	-0.462	-0.705	-0.986	-1.324	-1.752	-2.346
d (inches)	30.246	18.586	12.321	8.458	5.898	4.130	2.880	1.986	1.345	0.888	0.567	0.345	0.197	0.103	0.047	0.018	0.005
d (inches)	30.246	18.586	12.321	8.458	5.898	4.130	2.880	1.986	1.345	0.888	0.567	0.345	0.197	0.103	0.047	0.018	0.005
% PGA ( $A_s$ )	9.14%	13.72%	18.29%	22.86%	27.43%	32.01%	36.58%	41.15%	45.72%	50.29%	54.87%	59.44%	64.01%	68.58%	73.16%	77.73%	82.30%

Example 2





Calculations

Project 405 R2B  
 Calculations for Kmax REDUCTION

Page 1 of 3  
 Job No. 19434-04  
 Made By JRC Date 12/2/20  
 Checked By \_\_\_\_\_ Date \_\_\_\_\_

VER. 1A11.5.2 (AFTER NCHRP REPORT 611)

$$\text{Eq. 1A11.5.2-1} \rightarrow K_n = \alpha K_{n0} \quad [K_{n0} = K_{\max}]$$

$$\text{WHERE } K_{n0} = \alpha K_{n0} \\ \alpha = 1 + 0.01n(0.5B - 1)$$

WHERE  $n = \text{WALL HEIGHT (FT)}$

$$B = \frac{F_v S_1}{K_{n0}}$$

WHERE  $S_1 = \text{SPECTRAL ACCEL. COEFFICIENT AT 1 SECOND}$

$F_v = \text{SITE CLASS ADJUSTMENT FACTOR}$

KNOWN  
VALUES

$$\begin{aligned} &\rightarrow S_1 = 0.283 \\ &\rightarrow F_v = 2.034 \\ &\rightarrow K_{n0} = 0.503 \\ &\rightarrow H = 20 \text{ FT} \end{aligned}$$

$$\rightarrow B = \frac{F_v S_1}{K_{n0}} = \frac{(2.034)(0.283)}{0.503} = 1.144 \checkmark$$

$$\begin{aligned} &\rightarrow \alpha = 1 + 0.01n(0.5B - 1) \\ &\rightarrow \alpha = 1 + 0.01(20)[(0.5)(1.144) - 1] \\ &\rightarrow \alpha = 1 + 0.2(-0.428) \\ &\rightarrow \alpha = 0.914 \checkmark \end{aligned}$$

$$\rightarrow K_{n0} = \alpha K_{n0} = 0.914(0.503) = 0.4600 \checkmark$$

→ ASSUMING 1 TO 2 INCHES OF DEFORMATION IS ACCEPTABLE UNDER SEISMIC WORKING  $K_y = 0.5 \alpha K_{\max}$

$$\begin{aligned} &\rightarrow K_y = (0.5)(0.914)(0.503) \\ &\rightarrow K_y = 0.228 \checkmark \end{aligned}$$


**HARTCROWSER**

 Project \_\_\_\_\_  
 Calculations for \_\_\_\_\_

**Calculations**

 Page 2 of 3  
 Job No. \_\_\_\_\_  
 Made By \_\_\_\_\_ Date \_\_\_\_\_  
 Checked By \_\_\_\_\_ Date \_\_\_\_\_

EQ. AII.5.2-3 → NOTE THAT THE THIRD TERM IS INCORRECTLY WRITTEN AS  $\frac{1-K_y}{K_{n0}}$  INSTEAD OF  $1 - \frac{K_y}{K_{n0}}$  PER NCHRP

WE HAVE USED THE REFACTO EQ. AII.5.2-3 WITH THE CORRECTED NCHRP TERM.

$$\rightarrow \log d = -1.51 - 0.74 \log\left(\frac{K_y}{K_{n0}}\right) + 3.27 \log\left(1 - \frac{K_y}{K_{n0}}\right) - 0.80 \log K_{n0} + 1.59 \log(P_{Gv})$$

WHERE  $K_y$  = YIELD ACCELERATION  
 $P_{Gv}$  = 38 FVS. (IN/SEC)

$$\rightarrow P_{Gv} = (38)(2.034)(0.283) = \underline{21.874} \checkmark$$

$$\begin{aligned} \rightarrow \log d &= -1.51 - 0.74 \log\left(\frac{0.230}{0.4100}\right) + 3.27 \log\left(1 - \frac{0.230}{0.4100}\right) - 0.80 \log(0.4100) \\ &\quad + 1.59 \log(21.874) \end{aligned}$$

$$\rightarrow \log d = -1.51 - (-0.2228) + (-0.4884) - (-0.2698) + 2.1305$$

$$\rightarrow \log d = \underline{0.129} \checkmark$$

$$\rightarrow d = 10^{0.129}$$

$$\rightarrow d = \underline{\underline{1.345 \text{ INCH}}} \checkmark$$

$$\rightarrow 1. V(GV) = \frac{K_y}{K_{max}} = \frac{0.230}{0.4100} = 0.5 = \underline{\underline{50\%}} \checkmark$$



Calculations

Project \_\_\_\_\_  
Calculations for \_\_\_\_\_Page 3 of 3  
Job No. \_\_\_\_\_  
Made By \_\_\_\_\_ Date \_\_\_\_\_  
Checked By \_\_\_\_\_ Date \_\_\_\_\_FOR A GIVEN PERCENT OF Kmax  $\rightarrow 0.25 \times K_{max}$ 

$$\rightarrow K_y = 0.25 \times K_{max} = (0.25)(0.914)(0.503)$$

$$\rightarrow K_y = \underline{0.115} \checkmark$$

$$\rightarrow P_{GV} = (38)(F_v)(S_i) = (38)(2.034)(0.238)$$

$$\rightarrow P_{GV} = 21.874$$

$$\rightarrow \log d = -1.51 - 0.74 \log\left(\frac{K_y}{K_{max}}\right) + 3.27 \log\left(1 - \frac{K_y}{K_{max}}\right) - 0.80 \log K_{max} + 1.59 \log P_{GV}$$

$$\rightarrow \log d = -1.51 - 0.74 \log\left(\frac{0.115}{0.4100}\right) + 3.27 \log\left(1 - \frac{0.115}{0.4100}\right) - 0.80 \log(0.4100)$$

$$+ 1.59 \log(21.874)$$

$$\rightarrow \log d = -1.51 - (-0.4455) + (-0.4085) - (-0.2698) + 2.1305$$

$$\rightarrow \log d = \underline{0.927} \checkmark$$

$$\rightarrow d = 10^{0.927}$$

$$\rightarrow d = \underline{8.458 \text{ INCH}} \checkmark$$

$$\rightarrow 1. P_{GIA} = \frac{K_y}{K_{max}} = \frac{0.115}{0.503} = 0.2284 = \underline{22.84\%} \checkmark$$